WATER RISK ANALYSES AND STRATEGIES FOR AUTOMOTIVE MANUFACTURING

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
School of Mechanical Engineering

Georgia Institute of Technology
April 2015

WATER RISK ANALYSES AND STRATEGIES FOR AUTOMOTIVE MANUFACTURING

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[To the students of the Georgia Institute of Technology]

ACKNOWLEDGEMENTS

I wish to thank more people than I will be able to remember to write about. However, I will start with my wife who has followed me all across the country in order for me to pursue my Master's degree and who has been supportive throughout. I would not have been able to succeed at Georgia Tech without her. I also want to thank my advisor, Dr. Bert Bras. He has been an extremely great advisor, has always been very helpful, and been very supportive. I would also like to thank Julie Hawk, who has been very helpful with this thesis. In particular, reviewing the document and making sure it all made sense. In addition, Thomas Niemann, Heidi McKenzie, Sherry Mueller, Chul Kim, and Susan Rokosz for working with me to fully understand the topic and how it can be impactful.

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NOMENCLATURE

Abbreviation, Term, or Acronym – Definition (Source) [Unit]

Abbreviations

AQE – Aqueduct Water Risk Atlas (WRI)

ARWS – Annual Renewable Water Supply per person (WRI) [m^3/person/year]

AW – Access to Water (WRI, UN) [%]

BWS – Baseline Water Stress (WRI) [ratio]

CDP – Carbon Disclosure Project

CSR – Corporate Sustainability Report

EWS - Environmental Water Scarcity Index by Basin (IWMI) [ratio]

GS – Groundwater Stress (WRI) [ratio]

GWT – Global Water Tool (WBCSD)

GLOWASIS - Global Water Scarcity Information Service [EU] [ratio]

HAC – Hypothetical Automotive Company

IWMI - International Water Management Institute

LCA- Life Cycle Assessment

MAR – Mean Annual Relative Water Stress Index (UNH) [ratio]

PES - Areas of physical and economic water scarcity (IWMI) [ratio]

PPIW – Proportion of Total Population Served with Improved Water (UN) [%]

PYW – Production per Year per Worker

RFR – Return Flow Ratio (WRI, NASA) [ratio]

TRWR – Total Renewable Water per person (WRI) [m^3/person/year]

UNH – University of New Hampshire

UNICEF – United Nations Children's Fund

WFN – Water Footprint Network

WHO- World Health Organization

WRF – Water Risk Filter (WWF)

WRI – World Resource Institute

WWF – World Wildlife Foundation

Terms

Total Annual Available – Sum of total available water annually in a given watershed or location

Total Annual Withdrawals – Sum of total annual withdrawals of water by agriculture, industry, and municipalities

Water Consumption – is defined as freshwater withdrawals, which are evaporated or incorporated in products or waste, and therefore do not return to the source of origin. Water that is consumed by a water user and is not returned to the water supply

Water Discharge – Water that is output from a user back into the supply, but not necessarily of the same quality

Water Withdrawal – Water is that withdrawn by a water source by a user, but not necessarily permanently removed from the water supply

SUMMARY

The availability of clean fresh water is an issue in many parts of the world. The water use by companies to perform their operations has become increasingly scrutinized as a result. However, some companies have found it advantageous to examine their water use and water risks to develop a strategy for becoming a better steward of the water resources.

Some companies have found it advantageous to examine their water use and water risks to develop a strategy for becoming a better steward of water resources. This thesis examines the overall process of how water issues can be: A) accounted for and analyzed B) risks can be mitigated C) how the overall water picture can be viewed. Although the tools currently available do perform useful analyses, further standardization of metrics needs to occur before the results are truly cohesive. For example, water stress has largely been standardized, but a metric for drought risk has not. In addition, some of the results of the tools are not consistent, and further work is needed for the tools to be comprehensive. Additionally, this thesis examines the influences of direct and indirect water use and risks, such as the water use by employees and energy generation in the process of building vehicles.

Understanding the indirect impacts of water use is important, and can sometimes be significantly more impactful than the direct water use. Companies or organizations that have comprehensive water strategies can eliminate risk, lower costs, and help become better stewards of the water supply on which life depends.

CHAPTER 1 INTRODUCTION

1.1 Motivation

Water scarcity is already a significant issue globally. According to Millennium Development Goals Report (UN, 2012) 11% of the world's population lives without access to an improved source of drinking water, such as household water, or public taps. Water scarcity will become an issue of greater and greater importance in the future. Some NGO's dedicate significant resources to document and coordinate water issues.

The Carbon Disclosure Project (CDP) is a group that surveys a large number of companies on the issues that they face relating to sustainability. In the CDP Global Water Report 2013 (CDP, 2013) 70% of companies reported having identified water risk as a substantial business risk, and the majority reported risks were expected to impact operations within 5 years. Additionally, more than half of companies surveyed have already experienced detrimental impacts due to water. Companies, NGO's, and governments need to have some way to analyze the risks water issues pose.

1.2 Literature Review

In (Joost Schornagela, 2012) an outline for how to account for water use is given. The primary purpose of this paper is to strictly define a set of rules for industrial water accounting and analyze impacts based on that definition. Withdrawal is defined as water drawn into a facility; consumption is water used by the facility (not returned to any water source), and discharge is water that leaves the facility and returns to a watershed. With these accounting rules, the authors analyzed a variety of energy sources and their water consumption and withdrawal according to original water stress calculations. With the water use strictly defined, other water analysis can be examined, such as water stress and life cycle examination. For example, the authors calculate that with the current U.S. electricity grid mixture of energy sources, electric cars consume approximately three times as much water as conventional gasoline powered vehicles. Water accounting rules are needed because water use is required for industrial purposes, and if a company does not understand its water use and risks, it can incur financial losses and suffer brand damage. In addition, companies should understand their water use in the supply chain. The supply chain can encompass energy usage and materials suppliers, among other things. The local context of industrial water use is important. A high water use site can operate sustainably in a low water-stress location. However, even a low water use site may not be able to operate sustainably in a high water-stress location. The impact of water use by an industrial facility depends greatly on the exact location and the exact water use.

In vehicle manufacturing in particular, the water usage has become an area of concern for automotive manufacturers and the interests near the manufacturing operations. In (Semmens, Bras, & Guldberg, 2014) the lifecycle water usage of vehicles is examined, in particulate the original equipment manufacturers water usage. The main goal of the paper was to understand the direct and indirect water consumption per vehicle. Although the OEM reporting lacked consistency, some overall patterns were found such as the average water consumption for vehicle assembly and estimates of energy used in vehicle manufacturing. The main findings were that the per vehicle water usage was in general falling, but the indirect water usage (such as from electricity generation to support the facilities) could be substantial. If the reporting for the entire direct and indirect water usage is not carefully tracked, it can be difficult to determine the exact water usage in vehicles or any other type of manufacturing.

In addition to the direct need for water in manufacturing, the flow of water in economic terms can have a significant impact as well. In (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2007), approximately 22% of industrial water use is related to trade. The reduction of water supply in water stressed regions necessarily makes water more expensive in a given region. When the market is allowed to set the price of water, water is more expensive when supplies are constrained. Consumers have to spend more to access water, and that can leave water stressed regions at an economic disadvantage against regions with greater water supplies.

Tools are now publicly available that can potentially help a company assess the impact of its water use and risks in relation to their global operations and supply chains. In (Carlile, 2014) a number of these water strategy tools are examined and compared in depth. Three tools were specifically compared, the Global Water Tool and the India Water tool both by the World Business Council for Sustainability, and the Water Risk Filter by World Wildlife Foundation. By analyzing the risk assessments by these tools, one can better gauge the similarities and differences between them and how they can be used for future water resource planning.

In (Mueller et al., 2014) an overview of water tools and their use for automakers is given. Businesses have to take a more pro-active approach to water. One way to analyze the water situation is with water tools that provide water assessments. The tools have a variety of outputs, with some being more pertinent for business operations than others are. For example, "water stress is considered a more relevant assessment of water risk than water scarcity due to the many aspects included." (Mueller et al., 2014) The paper took a selection of locations and for the four tools analyzed a selection of water risks output by the tools. This included water availability, and seasonal availability. The availability of water varied greatly at different locations according to the tools. However, the results were not consistent, with one or more tools disagreeing with the overall trend for a location. The paper found that there is a great deal of water information in the public domain, but that there is a need for improvement in the datasets and metrics in order for the tools to become more useful for industry.

The water metrics used to analyze the water situation by the water tools require an in-depth understanding of what defines a stressed or acceptable water state. One widely used measurement for general water scarcity is the *Falkenmark indicator*. It is essentially a measurement of water stress described in *Macro-Scale Water Scarcity Requires Micro-Scale Approaches* (Falkenmark, Lundqvist, & Widstrand, 1989) the water stress measurement is defined as 1700 m^3 of renewable water per year per person as an acceptable threshold. Regions below this are considered 'stressed', regions below 1000 m^3 are considered to be experiencing 'water scarcity', and regions below 500 m^3 are considered to be in 'absolute scarcity'. This is significant because the work done in the study gives a range for a well-documented water metric that is commonly tracked for most regions.

In (Rijsberman, 2006) issues with different water metrics are discussed. One issue is that some high population areas will have a certain amount of stress listed by a metric even if the water supply is adequate. That is due to both a high population using water, and municipalities having the infrastructure capable of handling it. Although there may be a large population, the infrastructure may be capable of handling the use. Additionally, different government's or organizations have different capabilities when it comes to infrastructure, so specific regions need to be examined in depth to understand the difference between high stress due to calculation, or high stress due to a lack of infrastructure to handle the water need. Despite these and other issues, the 'water scarcity' metric define by Falkenmark is a very good metric that gives an indicative mark of the local water situation. Also mentioned in (Rijsberman, 2006) is that water scarcity will be an issue for the foreseeable future, and regions in Africa and Asia will have to do the most structural overhaul to supply the necessarily water for their populations.

In (Walsh, Murray, & O'Sullivan, 2015), the issue of companies reporting water is discussed. In particular, the comparison between requirements for current CO2 reporting and future water reporting is made. Currently, many countries require standardized reporting of the total CO2 generated for all direct and indirect operations of companies. There is the potential for this disclosure to be required for water in the future. Additionally, for manufacturing specifically, the authors project that by 2050 water use by the manufacturing industry generally will increase by 400%.

The ISO 14046 standard (ISO, 2014), which is the standard for water accounting and water footprint assessments came about because of the need for assessing and reporting water footprints. The terms "withdrawal" and "consumption" are given strict definitions in relation to water use. They are defined in the same manner as (Joost Schornagela, 2012) with withdrawal referring to removing water from a basin (even if it may be returned or is used temporarily) and consumption is water not returned to the basin. The ISO 14046 standard also goes into the practices for performing Life Cycle Assessments (LCA) of water use. Specifically, the process for determining the environmental impact of water use depending on the location, quality, and total use.

CHAPTER 2 UNDERSTANDING WATER TOOLS

2.1 Water Tools Overview

Several publically available water tools can be used to assess the impact of water risks and stress onto a group's operations and supply chains. Although there are differences between the tools (Carlile, 2014), the general idea is the same: with a few inputs, the basic water risks and stress can be quantified in a way that helps organizations see the impacts of water. Additionally, water tools typically can also serve as water accounting tools which follow the guidelines from (Joost Schornagela, 2012).

The main purpose of the three tools, Global Water Tool, Aqueduct, and Water Risk Filter, is to enable the user to understand the water risks and potential for environmental impact based on the usage and locations of facilities in an organization. All of the tools can be used to attempt to determine which locations in an organization are located in areas with water stress and water risks, such as flood occurrence. In order to give results, the tools use a combination of water metrics to identify particular risks or stresses. The metrics are conceptually detailed in Chapter 3.

2.2 Context of the Water Tools

Many companies are already experiencing water-related issues that affect business and/or government operations, as mentioned by CDP Water (CDP, 2013). Additionally, water risks for companies and investors are beginning to be included in financial risk analysis generally, not just in corporate sustainability reports (Herbst, 2009).The best way to currently estimate the water situation is to use a water tool, such as the Global Water Tool, Aqueduct, or Water Risk Filter. All of these tools provide insight into the water situation experienced by a company or organization.

In CDP Disclosures, companies such as GM and Ford use some combination of these tools in order to determine their water risks and stresses (Ford, 2013; GM, 2014b). In other words, the tools estimate the water stress, flood risk, or other water related metrics for the facilities affiliated with that organization. Automakers are already evaluating their water risks and making decisions about locations and resource allocation based on water risks (CDP, 2014). In an organization, water impacts can affect decisions in different ways. For the purpose of this thesis, a generic corporate hierarchy is used, and shown in Figure 1.

In general, the workers and site manager at manufacturing facilities are responsible for water use and accounting. However, their ability to influence the water policies, facility locations, or resource allocation is limited generally. Regional managers and vice-president level employees have the ability to allocate resources, influence water policies, and influence facility locations. In an organization, these employees are the ones that would find the water tools and the water analyses in this thesis the most useful and applicable. These employees can use the tools to determine which facilities have the highest risk exposure and which specific risks or stresses are present. This information is useful for executives and shareholders as well, but the work of using the tools is most likely in the domain of vice presidents or regional managers.

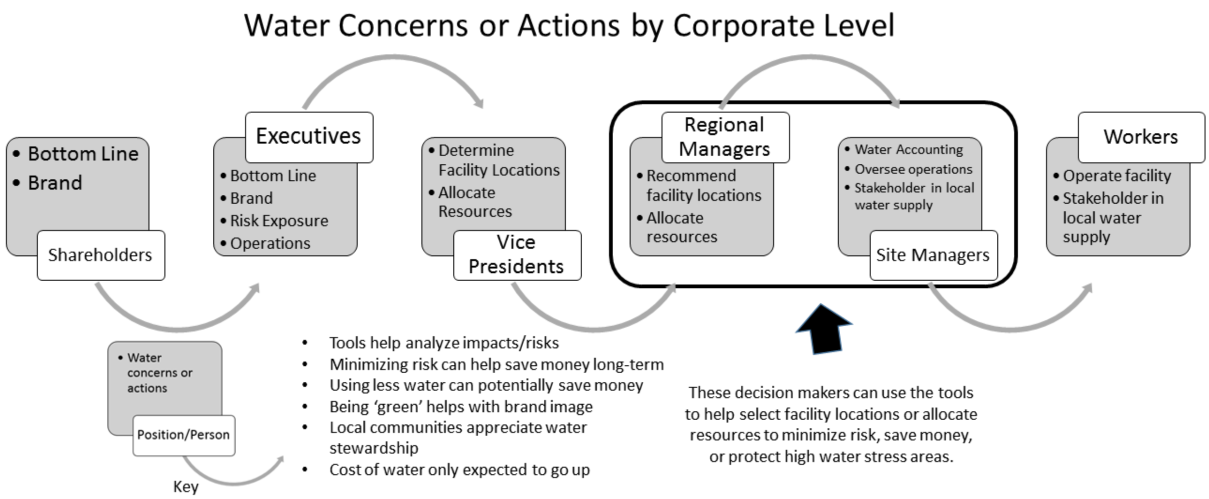


Figure 1 Water Influence in a corporate hierarchy

For example, in Volkswagen's 2014 CDP Water Report (VW, 2014e), Volkswagen outlines how their organizations approach water in their growth plans. VW does an assessment to ensure new production sites have available water and that VW understands any other environmental risks associated with that location. The VW outlook is given in Figure 2. Additionally, VW examines the water risk at current facilities, and the company attempt to alleviate any risks or problems.

W1.2
Have you evaluated how water quality and water quantity affects /could affect the success (viability, constraints) of your organization's growth strategy?

Yes, evaluated over the next 10 years

W1.2a
Please explain how your organization evaluated the effects of water quality and water quantity on the success (viability, constraints) of your organization's growth strategy?

Environmental aspects are important in each side assessment for new production sites. The resource water and its availability und risks are one of these environmental aspects.
For each site the water availability is evaluated before decisions for or against a potential new production site is made. Therefor there are information available for each site.
Each factory is audited (internal or external ISO 14001 audit) every year. If any shortages in the water supply would occur would this be a topic in the following audit and the site have to show how they try to solve these problems.
Volkswagen uses a risk management to identify, evaluate and to minimise potential risks for the company itself. The process includes the following steps:
1. Identification of the risks
2. Evaluation of the risks with their impact
3. Definition and execution of countermeasures
4. Controlling and reporting of risks and countermeasures
In these risk management all risks for the company are included. Also environmental risks e.g. water risks. For important risks in this sector an evaluation is made as well as definition of the problem and execution of countermeasures.

Figure 2 VW Response to CDP Questions W1.2 and W1.2a (VW, 2014e)

A specific example of this strategy is detailed in the VW CDP Water response regarding a facility in the Godavari river basin in India (VW, 2014e). VW believes that the facility is in a high water-stress location, so the factory emphasizes using water efficiently, and recycling as much water as possible (VW, 2014e). Because VW performed the analysis on water risks, they have been able to take steps to alleviate their water risk. This may just be one facility, but the VW CDP Water report has many instances of VW allocating resources or taking steps to mitigate negative water issues.

In addition to being a better steward of water resources, water management can have direct financial benefits. For example, according to VW's 2013 Sustainability Report (Volkswagen, 2014b): "At our Braunschweig (Germany) plant, a conductance-controlled water spray metering system in the paint-shop saves 34,380 m^3 of water, reducing overall costs by around €232,000." In addition to possible cost savings, understanding water risks can directly help a company avoid a disruption of operations. From VW CDP Water Report (VW, 2014e): "In the beginning of June 2013 the Chemnitz river levels increased dramatically after heavy rainfalls in the upstream areas. Because of the two critical water levels in the Chemnitz River in 2002 and 2010 a dam was built to ensure that the water cannot flow from the river in the factory. All risk management actions of the factory worked well. Several pumps had to be installed. Most streets around the river where closed and caused several transport problems." Although the steps VW took in this case likely did not save them money, it did help keep their facilities operating despite water levels in a nearby river.

Companies that are already experiencing water-related disruptions of supply or cost increases can benefit from using water tools to understand their water risks and impacts. The tools can also benefit companies that are not currently experiencing any negative impacts because all three include projections for future water situations. Using the water tools to assess risks can empower a company to choose locations in low-stress low-risk locations or to invest in water efficiency technologies. Using less water can result in cost savings as well. With the water tools being used by members of an organization that can influence allocations and operations, companies can leverage the information in a variety of ways.

2.3 Comparisons of Different Tools

The main purpose of the three tools (Global Water Tool, Aqueduct, and Water Risk Filter) is to enable the user to understand the water risks and potential for environmental damage based on the usage of an organization. All of the tools can be used to attempt to determine which locations in an organization are located in areas with water scarcity (or another water risk). In addition, the tools attempt to show areas where there is the greatest environmental damage by water usage.

2.4 Water Accounting

One issue with examining water from an organizational perspective is the definitions about water accounting. For example, water that is consumed in a process is handled differently than water that is used and then returned to the environment. Water that is consumed in the process is defined as consumption: think water being used in a soda. That water will not be returning to the watershed. Water that is discharged can be thought of as water that is used for cooling at power plants. The water is used, but then it is largely returned to the watershed from which it came. The quality of the discharged water can be important, but the general idea of discharge vs consumption is defined along those lines. This issue of water use and consumption definitions is strictly defined in Water Accounting (Joost Schornagela, 2012) and the key concept is best summarized in Figure 3. ISO 14046 (ISO, 2014) follows the same definitions, and expands them further into quality concerns and LCA.

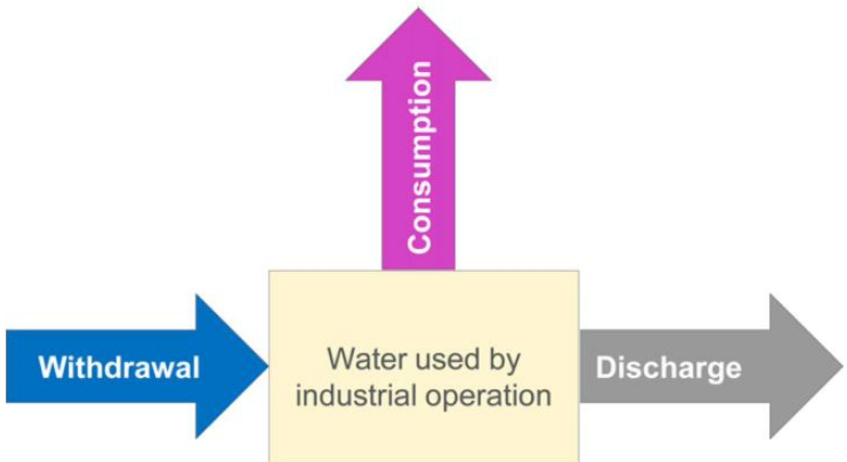


Figure 3 Off-Stream Water Use Defined (Joost Schornagela, 2012)

Having water use strictly defined allows different organizations to report on their water use in a consistent way. Although this definition is largely followed (Analytics, 2014a, 2014b; CDP, 2014), there is an unfortunate lack of consistency when it comes to water risks and stress whose definitions vary from tool to tool.

2.5 Overview of Each Tool

The general purpose of the water tools, to help organizations understand the impact of water, is similar between all of them. However, they each have slightly different philosophies on how to achieve this goal.

2.5.1 Global Water Tool by WBCSD

The Global Water Tool (GWT) by World Business Council for Sustainable Development

(WBCSD, 2013b) is a tool designed to help companies with reporting and accounting as well as analyze water metrics. The tool is broken down into two parts: an Excel workbook for inputting data and examining some results, and a mapping component that allows the company or group using the tool to map their facilities and water issues. To begin, the GWT needs raw water usage and location. The water usage is organized by type: surface water, municipally supplied, groundwater, or another source. The calculated stresses and risks are shown in the Excel workbook, and some of the water risks and stresses are shown in the mapping component.

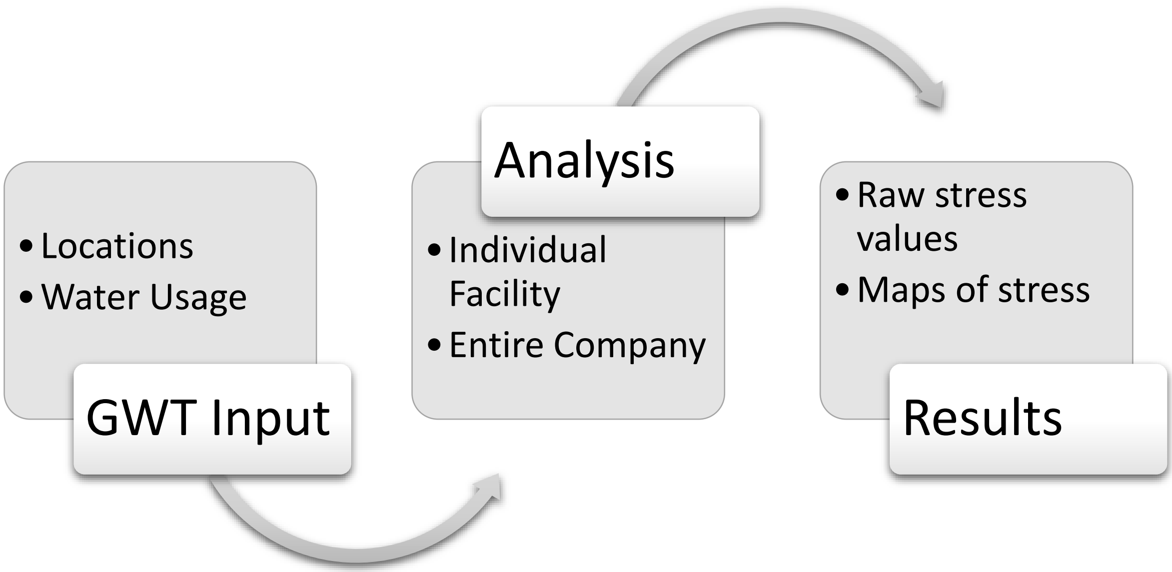


Figure 4 General Workflow of Global Water Tool

The GWT has useful watershed level baseline water stress information, and also has links to the CDP Water Questionnaire and can help with water accounting generally. Neither of the other tools has that capability. It is also easy to understand exactly where the data came from and what the data implies. The main problem with the GWT is that the usefulness for different types of water risks or stresses is limited. It also has very basic mapping abilities.

2.5.2 Water Risk Filter by WWF

The Water Risk Filter (WRF) by the World Wildlife Foundation (WWF, 2014b) is similar in some ways to the GWT but different in others. They both have location and water usage as inputs, but the WRF goes a step beyond those requirements and has an extensive survey requirement. The output of the WRF is different as well as the WRF has “heat maps” that show the risks at a facility. Similar to the GWT, the WRF has a mapping component for different water risks and stresses. Unlike the GWT, there is the ability to “weigh” the importance of different risks and stresses and how much they affect the overall result. The result is a series of heat maps for each location, and a mapping component to allow a company or group to see their water risks and stresses globally.

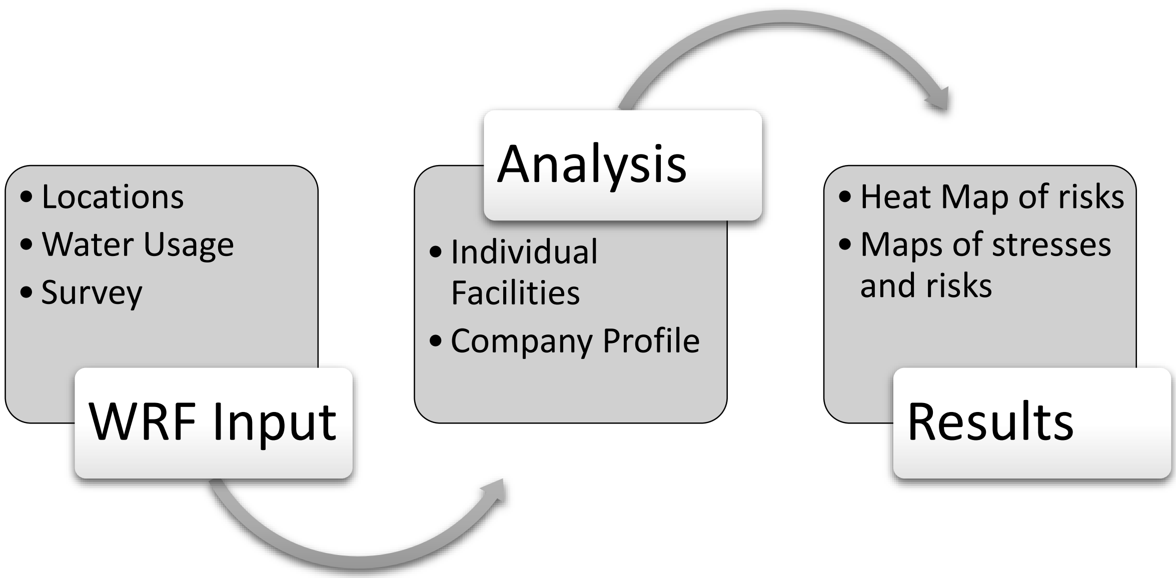


Figure 5 General Workflow of Water Risk Filter

2.5.3 Aqueduct by WRI

Aqueduct by World Resource Institute (WRI, 2014) is similar to the other tools, however there are a few significant differences. First, Aqueduct is browser based. All of the information is held by WRI, although it can be exported into an Excel workbook. Similarly to the GWT and WRF, its mapping function can plot various risks and stresses from both watershed and country level data sources. The key difference is the weighting function. Aqueduct has preset weights for different industry types, but it allows the user to mix and match any combination of weights of any risk factor. For example, the GWT can only plot one risk or stress factor at a time, like baseline water risks. Aqueduct can plot baseline water risk at a certain weight, and combine that with flood risk at a given weight. This capability allows the group or company using the tool to find an overall risk factor dependent only on the types of risks and stresses they are concerned. Although that concept sounds abstract, it is very useful when examining which water issues could affect a company directly.

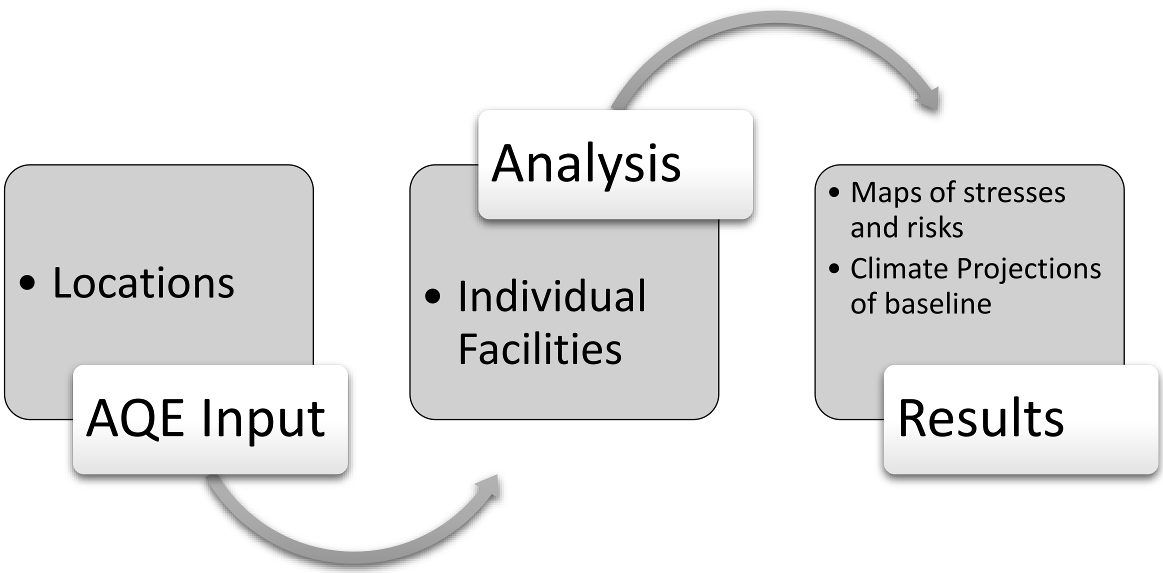


Figure 6 General Workflow of Aqueduct

2.6 Summary of Chapter 2

The water tools examined in this thesis are the Global Water Tool (GWT), the Water Risk Filter (WRF), and Aqueduct (AQE). Each has a different workflow, but the general idea of each one is the same: input information about operations, the tools give results in the form of metrics, and the results are mapped, given for individual facilities, or given as a total company profile. The types of metrics and a general overview of key metric concepts are given in Chapter 3. The GWT and WRF also have water accounting capabilities that match standard reporting practices, such as CDP Water Disclosure.

CHAPTER 3 WATER METRICS

3.1 Water Metrics Overview

Previously in this thesis, the concept of a water metric was discussed in relation to work done by Falkenmark (Falkenmark et al., 1989) and Rijsberman (Rijsberman, 2006) relating to their work with water stress and scarcity. Water metrics are ways to assess a particular aspect of the state of water in a location or country. For example, the Falkenmark indicator is a measure of the water stress in a particular location measured in m^3/person/year. Most water metrics are collected for entire watersheds or countries and are plotted on maps or analyzed on a location-by-location basis. The water tools examined in this thesis contain multiple databases of a wide variety of water metrics. In order to understand the water situation of a company or even one facility, it is important to understand the basic concepts behind how water metrics work.

3.2 Country and Watershed Level Water Metrics

3.2.1 Country Level Water Metrics

Country level metrics are values that are consistent for an entire country. For example, the GWT has "Total Renewable Water per Person" (TRWR) country level water stress. The metric is shown in Figure 7. The metric is described as: "the total annual internal renewable water resources per inhabitant." (WBCSD, 2011b)

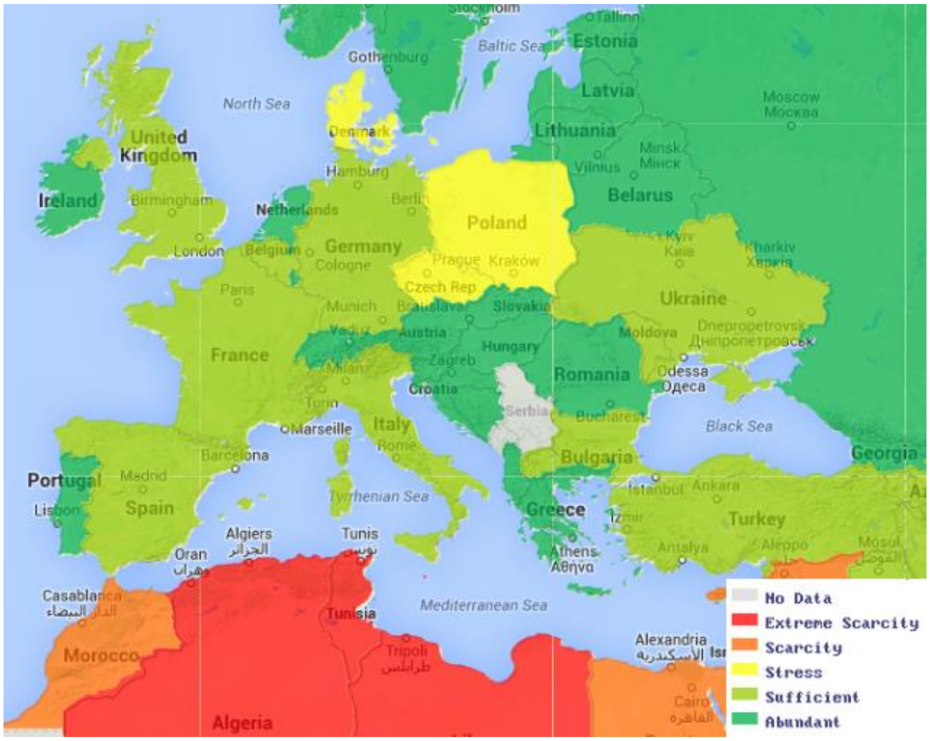


Figure 7 GWT Country Total Renewable per person (2008)

3.2.2 Watershed Level Water Metrics

Watershed level metrics are not constrained by country borders and their resolution only depends on the data collection. For example, the GWT has "Annual Renewable Supply per Person" (ARWS) on a watershed level. The metric is described as: "Indicates the average annual renewable water supply per person for individual river basins as of 1995." (WBCSD, 2011b) The metric for Europe is shown in Figure 8.

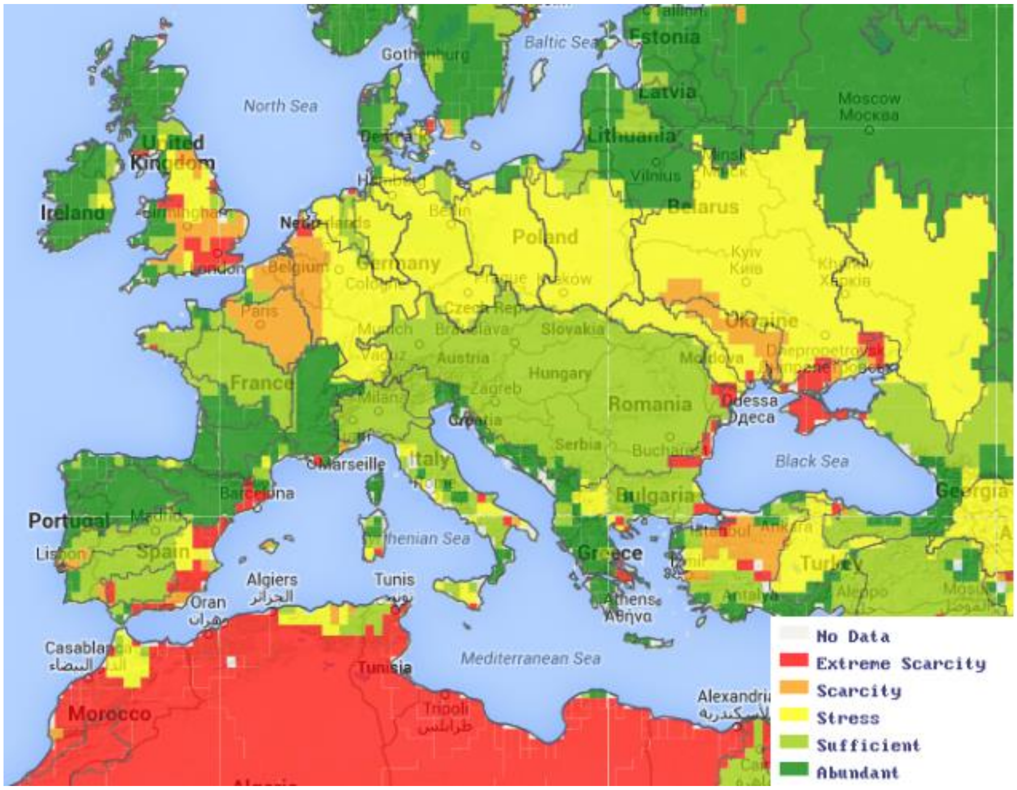


Figure 8 GWT Watershed Annual Renewable per person (1995)

3.3 Water Metric for Specific Location and Mapped Water Metrics

3.3.1 Water Metrics for Particular Location

In all of the tools examined in this thesis, there is the ability to output all the metrics for a particular location. For example, Figure 9 shows WRF metrics for the USA Car facility. Only a selection of metrics is shown in Figure 9 to demonstrate how the results for an individual facility can be shown directly from the tool. This output allows for numerical comparison as well as examining all of the metrics for a particular location. This is difficult when mapping or examining the total risk because each metric is not as distinguishable as they are in Figure 9.

Name of facility	Country	River basin	Annual monthly average scarcity (WFN)	*Annual monthly average scarcity (GLWOASIS)*	Number of months severe scarcity (WFN)
USA Car	United States of America	St.Lawrence	2	5	2

Figure 9 WRF Selection of Water Metrics for USA Car facility

3.3.2 Water Metric Plotted on Map

The main advantage of plotting a metric on a map is that it allows the user to see the metric visually. Typically, the user can examine regions with which they are familiar, which can help give context.

For example, Figure 10 shows most of the North American continent with the flood risk metric plotted. The Flood metric from WRF is a measure of the number of major floods, intense events covering large areas over extended periods of time (Brakenridge, 2015), from 1985-2005. Figure 11 shows the same flood occurrence metric as Figure 10. The purpose of showing both the North American and Southeast Asian regions is that if the user is familiar with one region, that map can give context for other parts of the world with which the user is not as familiar.

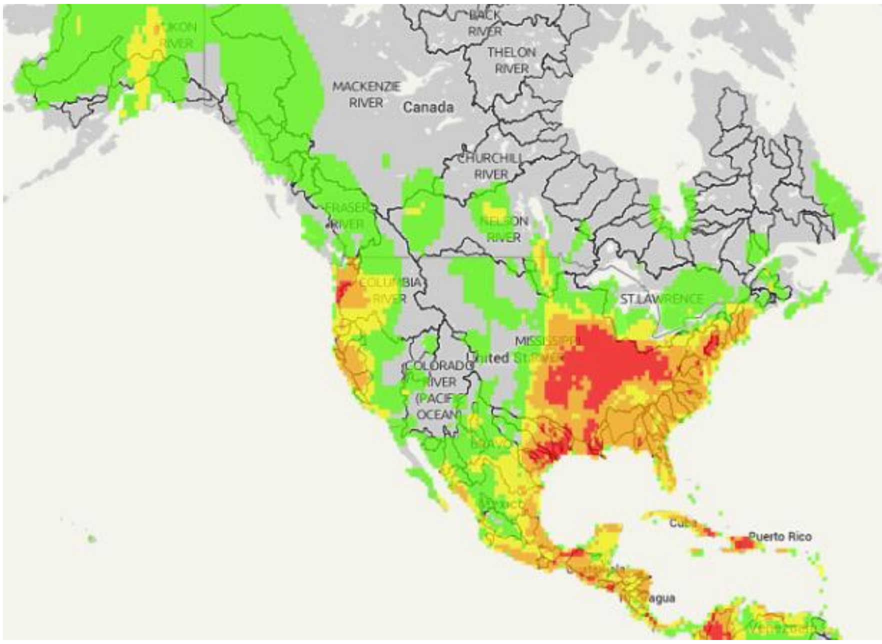


Figure 10 Flood Occurrence North America from WRF

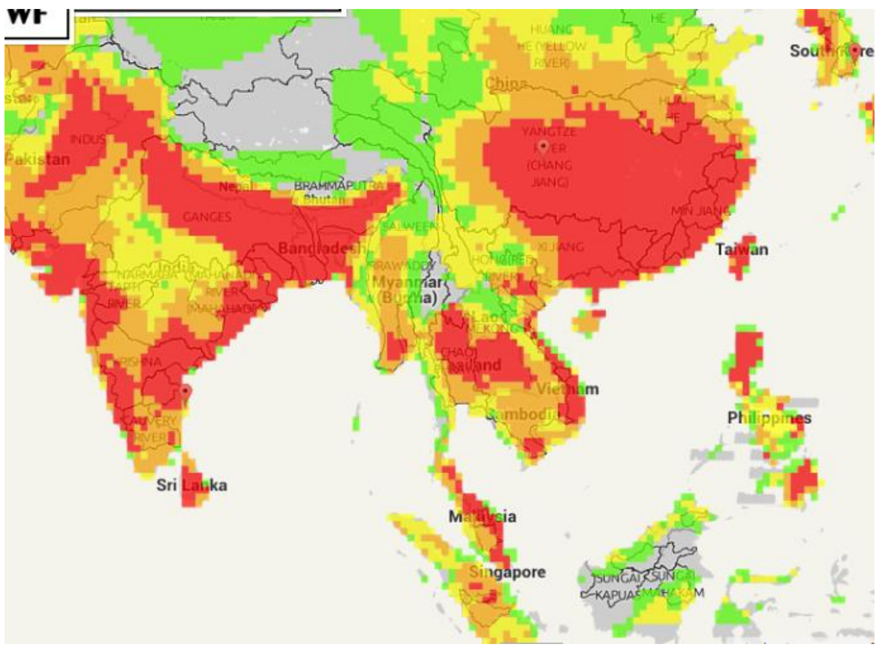


Figure 11 Flood Occurrence Southeast Asia from WRF

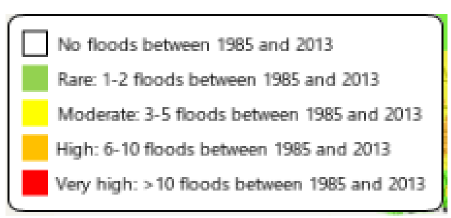


Figure 12 WRF Flood Occurrence Key

The Flood metric is based on historical information that is shown in Figure 12. Each metric is based on a dataset, and for the WRF Flood metric, the database is the University of Colorado Flood Observatory. Once the scale, dataset, and definition are understood, the metric can be useful. For example, from the maps it is obvious which areas are more prone to flooding based on the historical data. It may be wise to avoid building manufacturing facilities in these locations because of the risk of a shutdown or disruption due to flood.

3.4 Survey, Historical, and Scientifically Measured Data

Water metrics generally fall into one of three categories of collection. Survey results, historical data, and measured data. Survey data works exactly as it intuitively sounds. For an example of a survey metric, the GWT includes a metric for "Proportion of Total Population Served with Improved Water" (PPIW Figure 13), which is calculated by a combination of public questionnaires and household surveys. Typically survey based databases are country-level.

Historical metrics are based on tracking how often an even occurred over time typically by an academic group (such as the University of Colorado) whose database is also used by Aqueduct (Paul Reig, 2013).

Figure 13 GWT PPIW of South America (percentage)

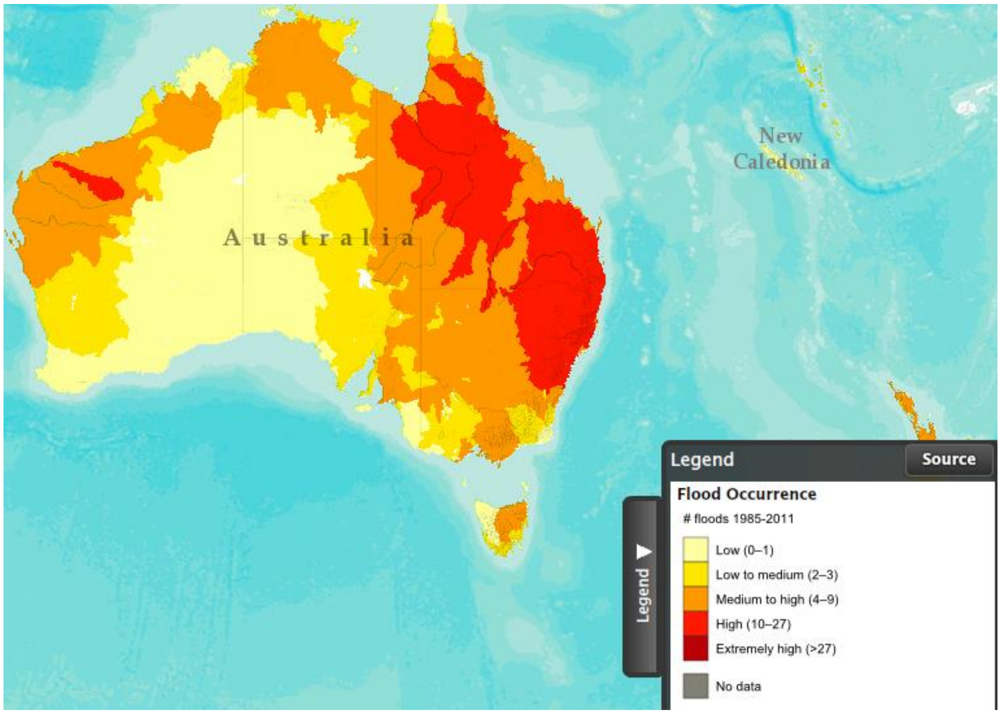


Figure 14 Aqueduct Flood Occurrence for Australia

An example of a scientifically measured water metric is the GLOWASIS, Global Water Scarcity Information Service (GLOWASIS, 2015), Water Stress in the WRF. The data collection for this metric is a combination of on-site measurement and information measured by satellites ("GLOWASIS," 2015). The Water Stress in the WRF does not follow any geographic constraints and is limited only by the resolution of the data. (Scientifically measured metrics typically follow watershed boundaries or are constrained by the resolution of the data). To describe the purpose behind GLOWASIS, this excerpt was taken from the website: “The objective of the project GLOWASIS is to pre-validate a GMES Global Service for Water Scarcity Information. In European and global pilots it will combine hydrological models with in-situ and satellite derived water cycle information, as well as statistical water demand data. GLOWASIS is set up as an open data portal, where water scarcity model time series and relevant satellite derived water cycle parameters can be downloaded.”(GLOWASIS, 2013)

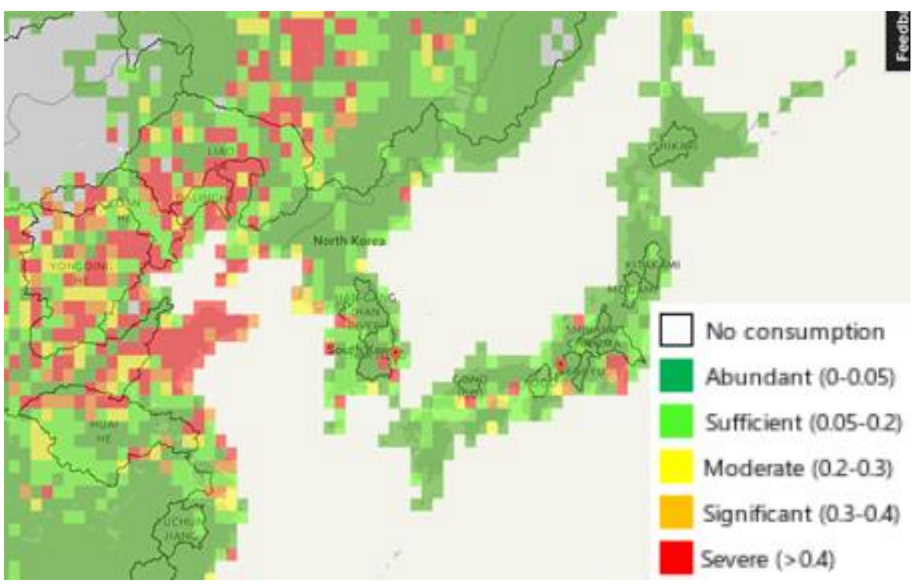


Figure 15 WRF GLOWASIS Water Stress for Korea, Japan, and Parts of China and Russia as measured by EU satellites and mapped by the WRF

3.5 Data Sources

The three tools covered in this thesis use information aggregated from a variety of sources. Most of the sources of water data come from academic NGO's or universities (Such as WRI and the University of New Hampshire). Figure 16 does not include every organization that contributed to the tools, but it shows a few trends. First, all of the tools use information from the UN, CDP, and WRI. Second, the GWT does not use any privately held company water analysis. Both WRF and Aqueduct use water information collected for private purposes and shared publically. In addition, the WRF is heavily dependent on the WWF and its own data collection for a significant portion of the WRF analysis.

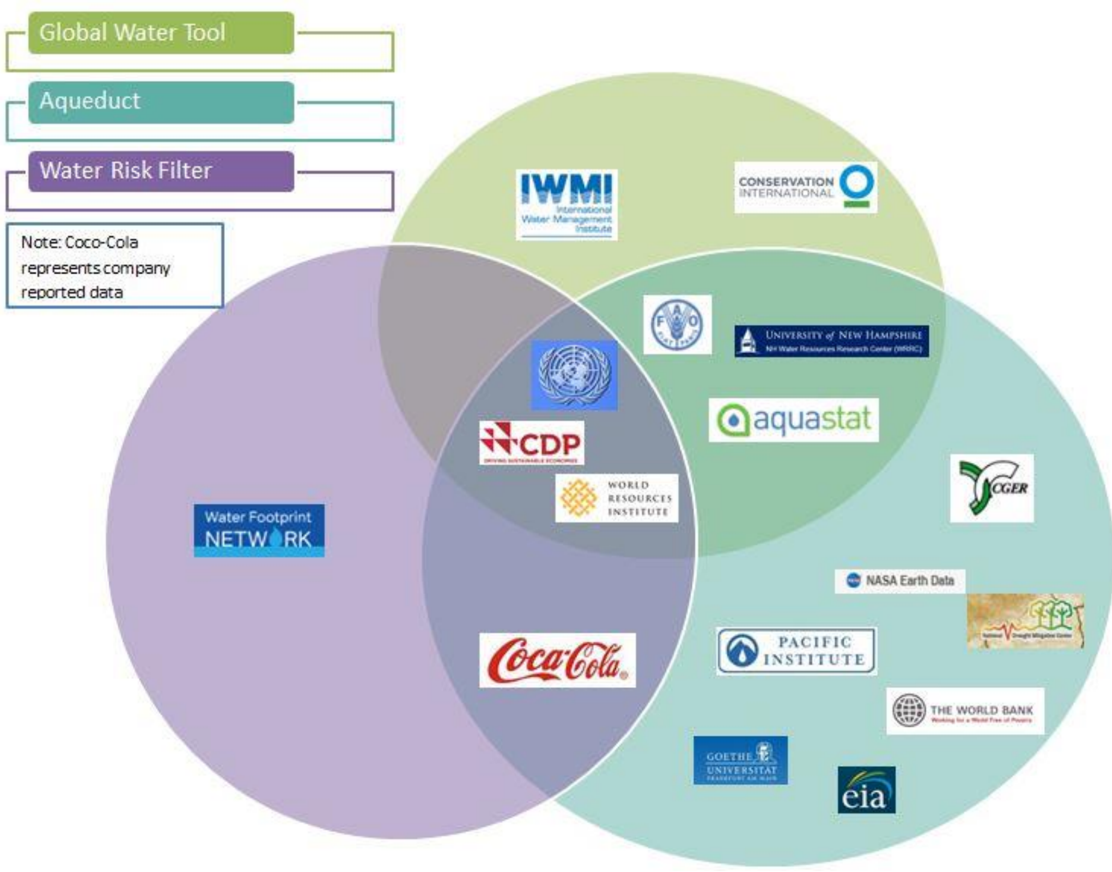


Figure 16 Venn diagram of Data Sources for the Water Tools

(Note: Coca-Cola symbol represents companies' public information; the remaining logos do correspond with a specific group)

3.6 Inputs for the Tools

Each tool requires different inputs in order to get information about the water situation for a company or organization. The WRF has a substantial questionnaire that covers a wide variety of topics related to water. The GWT inputs are essentially the locations, water use, and supplier locations and water use (if applicable). For this thesis, no suppliers were examined. In other words, only the direct operations of automakers will be examined. AQE uses only the locations of the facilities, but supplier locations can be included as well. This is summarized in Figure 17.

Input	GWT	WRF	Aqueduct
Facility Locations	☑	☑	☑
Water Use	☑	☑	☐
Water Quality	☐	☑	☐
Supplier Information	☑	☑	☑
Regulation Information	☐	☑	☐
Nearby Stakeholders	☐	☑	☐
	☑	Has at least one input for category	
	☐	No metric for category	

Figure 17 Inputs for GWT (WBCSD, 2013a), WRF (WWF, 2015d), and AQE

3.7 Metric Overview

Each tool has a different set of water metrics and types of projections. These differences are shown in Figure 18 and Figure 19. The general idea of the checklists is to document whether or not the tools incorporate the metric into the water risk and stress assessment. The tool gets a check if the tool has metric that accounts for the water issue. For example, the GWT has multiple water stress and scarcity metrics and Aqueduct only has one, but for comparison, both receive a checkmark.

General Type of Index	GWT	WRF	Aqueduct
Water Stress/Scarcity Index	☑	☑	☑
Biodiversity	☑	☑	☑
Groundwater	☐	☑	☑
Pollution	☐	☑	☐
Climate Change Mitigation	☐	☑	☐
Priority River Basins	☐	☑	☑
Floods	☐	☑	☑
Drought	☐	☑	☑
Hydropower/Upstream Storage	☐	☑	☑
Agricultural Indicators	☑	☑	☐
Reputational	☐	☑	☑

☑	Has at least one metric for category
☐	No metric for category

Figure 18 Checklist of overlapping metrics each of the three tools (Paul Reig, 2013; WBCSD, 2011b; WWF, 2015d)

General Type of Index	GWT	WRF	Aqueduct
Water Stress/Scarcity Index	☑	☑	☑
Multiple Scenarios	☐	☐	☑

☑ Has at least one metric for category

☐ No metric for category

Figure 19 Checklist of overlapping projections of the three tools (Paul Reig, 2013; WBCSD, 2011b; WWF, 2015d)

3.8 Chapter 3 Summary

Water metrics are now outlined with a few key general properties to help with their meaning. Some are collected for watershed, others for countries, and some follow no geographic constraints. Most can generally be plotted on maps or analyzed on a location-by-location basis. No matter the context of the metric, it is important to understand the basic concepts and to understand the type of data examined. Each tool uses a different combination of water metrics, which will be covered in each tool's individual chapter (Chapters 5, 6, and 7).

CHAPTER 4 AUTOMOTIVE INDUSTRY RELEVANT DATA

4.1 Purpose of Survey of Current Automotive Manufactures

In order to use the water tools or perform any analysis with respect to the automotive industry, the first step is to collect publically available relevant data. For example, all of the tools use the location of facilities as an input. For this study to be relevant, the facilities analyzed will need to be realistic, and be 'located' in areas that have automotive production. It would not make sense to analyze an automotive factory located in Alaska, because there are no automotive factories there.

4.1.1 Regions with Active Automotive Manufacturing

Some automakers provide a list of their manufacturing facilities on their website. For the purposes of examining the water issues, the locations for the Hypothetical Automotive Company (HAC) needed to be located in areas of active automotive manufacturing.

Figure 20 Hypothetical Automotive Company Locations (shown as blue triangles)

Some automakers list their global facilities: Volkswagen (Volkswagen, 2014a), Hyundai (Hyundai, 2014), Ford (Ford, 2014b), BMW (BMW, 2014a), and Subaru (under Fuji Heavy Industries) (Domestic, 2014) (Overseas, 2014). From those corporations' locations, the HAC locations shown in Figure 20 are located in areas of active automotive manufacturing. The main regions are Germany, Michigan in the United States, central Mexico, Chennai India, Coastal Brazil, Central China, South Korea, and Japan.

2013 PRODUCTION STATISTICS

Country	Cars	Commercial vehicles	Total	% change
China	18,085,213	4,031,612	22,116,825	14.8%
USA	4,368,835	6,697,597	11,066,432	7.1%
Japan	8,189,323	1,440,858	9,630,181	-3.1%
Germany	5,439,904	278,318	5,718,222	1.2%
South Korea	4,122,604	398,825	4,521,429	-0.9%
India	3,138,988	741,950	3,880,938	-7.0%
Brazil	2,722,979	989,401	3,712,380	9.1%
Mexico	1,771,987	1,280,408	3,052,395	1.7%

Figure 21 OICA 2013 Top Producing Countries (OICA, 2013)

To further confirm the validity of the location for the HAC generally, the locations were also based on which countries had the highest vehicle production from the International Organization of Motor Vehicle Manufacturers 2013 database (OICA, 2013). The countries used in the hypothetical list are the top producers from the OICA list.

Table 1 Vehicle Water Usage by Various Automakers (GM, 2014a), (VW, 2014d), (Ford, 2014a), (Peugeot, 2014), (Nissan-Renault, 2014), (Fiat-Chrysler, 2014), (Daimler, 2014), (BMW, 2014b)

	Most Recent Water Usage per Vehicle Globally (m^3/vehicle)	Year of most recent	Target Reduction	Year of Goal
GM	4.39	2013	15%	2020
Volkswagen	4.55	2012	25%	2018
Ford	4.00	2013	30%	2015
Peugeot SA	4.00	2013	Numeric	2020
Renault	7.02	2013	15%	2016
Fiat-Chrysler	3.23	2013	40%	2020
Daimler	5.22	2013		
BMW	2.18	2013	45%	2020

Table 2 GM Total Water Usage and Select Intensities (GM, 2014a)

GM Total Water			
Withdrawn		42,589	ML
Discharged		34,923	ML
Consumed		7,666	ML
Volume of Recycled		18,879	ML
Water Intensity Avg. Mexico		0.0021	ML per vehicle
Water Intensity Avg. World		0.0046	ML per vehicle

Table 3 VW Total Water Usage and Select Intensities (VW, 2014e)

VW Total Water			
Withdrawn		54,417	ML
Discharged		35,419	ML
Consumed			ML
Volume of Recycled		3,800	ML
Water Intensity World Avg.		0.00434	ML per vehicle
Water Intensity Germany Avg.		0.0031	ML per vehicle

4.1.2 Public Water Usage Data from Current Automotive Manufacturers

Most automakers release a Corporate Sustainability Report that contains a variety of relevant information for water research. One key number for any examination is the water use per vehicle. Table 1 shows a collection of the per vehicle water usage in m^3 per vehicle, and from that data HAC values are within that range it is apparent that to manufacture a car, it takes from 2-7 m^3 of water on average. .

Additionally, CDP has a Water Information Request that some automakers report some of their water usage through. These reports are particularly insightful because the companies are encouraged to disclose facility specific information as well as how the company perceives water issues generally. GM and VW have both responded publicly to the CDP 2014 Water Information Request. For the purposes of creating a realistic HAC, their total water usage information is collected in Table 2 and Table 3.

Although these numbers will not be used directly in the HAC, their values provide a gauge for a range of potential values for the HAC. The water intensity values reported in the CDP Reports closely correspond with the companies' sustainability report numbers, as shown converted into m^3/vehicle in Table 4.

Table 4 Reported Water Intensity Values from CDP Reports (converted to m3/vehicle) and Corporate Sustainability Reports (GM, 2014a) (GM, 2014b) (VW, 2014d) (VW, 2014e)

Reported Water Intensity Values			
CDP GM World		4.39	m^3/vehicle
CSR GM World		4.60	m^3/vehicle
CDP VW World		4.55	m^3/vehicle
CSR VW World		4.34	m^3/vehicle

Although there is a slight discrepancy, considering the magnitude of the values these numbers are calculated from (Total vehicles produced and total water usage in a given year) and that the CDP reports request mega-Liters (unit conversion), the values are good representations of the water intensity for each manufacturer. These values are used to give a representative water intensity for HAC facilities. Additionally, the CDP Reports contain facility specific water usage by a selection of GM and VW facilities, shown in Table 5 and Table 6.

Table 5 Water Usage Reported by GM (GM, 2014b)

GM Water Usage By Reported Facility (mega-Liters)						
	Country	Surface	Groundwater	Municipal	Discharged	Consumption
San Luis Potosi	Mexico		126.7		0	126.6
Silao	Mexico		610		118.4	491.6
Nairobi	Kenya			38.3	15.6	22.6
Cairo	Egypt			148.2	118.6	29.6
Port-Elizabeth Straundale	South Africa			104.6	96.3	8.4
Qingdao	China			830.8	402.3	428.5
Yantai	China			2349	1184	1165.4
Elizabeth	Australia			362.2	177.2	185

Table 6 Water Usage Reported by VW (VW, 2014e)

VW Water Usage by Reported Facility (mega-Liters)							
	Country	Surface	Groundwater	Municipal	Discharged	Consumption	Total
VW South Africa (Uitenhage) Engines	South Africa			382.54	167.22	NA	549.76
VW Sachsen (Chemnitz) Engines	Germany		95.95	29.42	54.59	NA	179.96
VW Puebla Mexico	Mexico	309.37	1380.64		1617.61	NA	3307.62
VW India Pune JV Total Workforce	India			255.63	153.6	NA	409.23
ChanChun, Chengdu, Nanjing, Shanghai, Anting, Yizheng Dalian, Urumqui	China			15510.48	12302.31	NA	27812.79
Rest of World		3.65	331.22	2602.12	1707.24	NA	4644.23

These water intensity values can be used to help create a realistic water usage profile for the HAC facilities. The intensities should be around 4 m^3/vehicle depending on the region, and water usage profiles typically contain municipal water sources with occasional surface or groundwater sources. Most facilities total water usage should be between 50,000 m^3 and 1,000,000 m^3 (50 mega-Liters to 1000 mega-Liters). These numbers correspond with all of the collected data, and the agreement between automakers and varying reports validates them.

4.1.3 Public Production and Worker Information from Current Automotive Manufacturers

In order to have realistic production and worker information for the HAC, current automaker information needed to be collected. Although the HAC is only a representation, having a valid set of values for production and workers at each facility is important to ensure that the work with the water tools is useful.

Volkswagen lists their facilities and many production and worker figures publically (Volkswagen, 2014a) (Bentley, 2013). Though the information is not complete for all facilities, there are a substantial number available. Ford (Ford, 2014b), Subaru (Domestic, 2014) (Overseas, 2014), Hyundai (Hyundai, 2014), BMW (BMW, 2014a), and Fiat-Chrysler (FCA, 2014) have similar public references. The information from these automakers was used to create the HAC locations. All of the HAC locations are located close to, or exactly at, a location from one of these automakers. For example, the USA Car and Truck locations are located near Detroit where Ford, GM, and FCA all have substantial factories. The India Car and Truck are located near Chennai, India, which is a very industrial area with automotive production. The Germany Car location is located near numerous vehicle factories. Mexico Car, China Car and Truck, Japan Car and Truck, South Korea Car, and Brazil Car and Truck are all located close to other automotive manufacturing locations as well. The notable locations are the UK Super Luxury Car location, which is loosely modeled from Bentley (Bentley, 2013) and the two powertrain locations: Germany Engine and Brazil Transmission. Those are loosely based on Salzgitter Germany VW (VW, 2014a) and the VW Brasil engine factory in Sao Carlos (VW, 2014c).

Figure 22 BMW Global Facilities (BMW, 2014a)

Figure 23 VW Global Facilities (Dooley, Kyle, & Davies, 2013; FCA, 2014; Volkswagen, 2014a)

Figure 24 FCA North America Locations (FCA, 2014)

VW, Hyundai, and BMW also listed the employees and production estimates for most of their facilities. This information is useful for two main reasons: the production numbers will give and idea of the water usage and the worker numbers will allow an indirect water usage number to be calculated. Table 7 is a collection of the VW production plants public information. That information can be compared with other automotive manufacturers' public information in order to ensure that the HAC has realistic worker and production data. The information in

Table 8 from Hyundai and Table 9 from BMW contain worker and production information, and although the numbers vary from manufacturer to manufacturer, they are close. For VW, Table 7 shows the average vehicle, powertrain component, or super luxury vehicle produced per year per worker. In other words, the average VW factory (average of the factories listed above) produced 29 vehicles per worker in a given year. The metric "Production per Year per Worker" (PYW) is created to show that relationship. These values help to make the PYW factor scalable for any size factory. There are differences between manufacturers, as would be expected.

Table 10 demonstrates that for a standard automotive factory, it is reasonable to have a value for PYW from 29-90. For a powertrain component factory, a much higher value of PYW is expected in the range of 400-500. For Super Luxury facilities, such as Bentley or Rolls Royce, the PYW value is much lower in the single digit range.

For the production total for a facility, the pattern is generally the same. For powertrain or component factories, per year production is typically around 500,000 units. For standard automotive assembly, the total production can range from 50,000 – 1,000,000 units depending on the factory. For Super Luxury facilities, the number is typically in the thousands.

Table 7 VW Production and Workers (Volkswagen, 2014a)

VW Production and Workers by Reporting Facilities		
Facility	Production	Workers	Prod/Year/Worker
VW South Africa (Uitenhage)	100,000	4,381	22.8
VW Chattanooga (USA)	150,000	1,700	88.2
VW Cordoba (Argentina) Tran	670,000	1,500	446.7
VW Pacheco (Argentina)	60,000	3,600	16.7
VW Sao Jose Dos Pinhais (Brazil)	317,550	24,000	13.2
VW Sao Carlos (Brazil)	1,387,000	24,000	57.8
VW Puebla (Mexico)	300,000	15,109	19.9
VW Pune (India)	130,000	3,572	36.4
VW Chanchun JV (China)	600,000	9,800	61.2
VW Sarajevo (Bosnia-Herzegowina)	3,500	308	11.4
VW Chemnitz (Germany)	755,000	1,000	755.0
VW Dresden Phaeton (Germany)	6,000	800	7.5
VW Salzgitter (Germany)	2,555,000	6,000	425.8
VW Wolfsburg (Germany)	807,000	48,000	16.8
VW Zwickau (Germany)	365,000	6,200	58.9
VW Polkowice (Poland)	600,000	1,200	500.0
VW Pamplona (Spain)	300,000	5,000	60.0
VW Bratislava (Slovakia)	220,000	7,500	29.3
Bentley Crewe (UK)	10,000	4,000	2.5

Capacity is in yellow

Component production in Blue

Luxury in Red

No commercial or industrial vehicles

If vehicle production and component export were listed, just vehicle production was listed on chart

Table 8 Hyundai Production and Workers (CZ, 2014; Hyundai, 2014; TR, 2014; USA, 2014)

Hyundai Production and Workers						
Facility		Production		Workers		Prod/Year/Worker
HY Ulsan (SK)		1,500,000		34,000		44.1
HY Asan (SK)		300,000		part of Kaesong IC		
HY Alabama (USA)		399,500		3,000		133.2
HY India (2 Factories)		633,006				
HY Czech		303,000		3,300		91.8
HY Turkey		200,000		1,700		117.6
HY Russia		200,000				
HY Brazil		167,000				
Capacity is in yellow						
			If vehicle production and component export were listed, just vehicle production was listed on chart			
Component production in Blue						
Luxury in Red						
No commercial or industrial vehicles						

Table 9 BMW Production and Workers (BMW, 2014a)

BMW Production and Workers by Reporting Facilities						
Facility		Production		Workers		Prod/Year/Worker
BMW Dingolfing (Germany)		340,000		18,500		18.4
BMW Hams Hall (UK)		400,000		800		500.0
BMW Oxford (UK)		191,000		3,800		50.3
BMW Rosslyn (S Africa)		53,000		1,700		31.2
BMW Spartanburg (USA)		300,000		7,000		42.9
RR Goodwood (UK)		3,500		1,300		2.7
Capacity is in yellow						
			If vehicle production and component export were listed, just vehicle production was listed on chart			
Component production in Blue						
Luxury in Red						
No commercial or industrial vehicles						

Table 10 Averages for per Year per Worker Production

Averages for Production and Workers						
Automaker		Average Vehicle PYW		Average Component PYW		Average Super Luxury PYW
VW		29		437		5
BMW		36		500		3
Hyundai		90		NA		NA

There are also regional differences. Although VW is the only source for Table 11, a few trends can be understood. Intuitively, Asian, European, and North American facilities had the highest production. This is likely due to those regions being the largest markets for car production generally (OICA, 2013). Those regions also contain countries where labor costs are higher, such as Japan or Italy, which would encourage automation (Labor, 2011).

Table 11 VW Group Facility Averages by Region (Volkswagen, 2014a) including capacity figures

VW Regional Production per Worker and Production			
	Regional PYW (no luxury)		Production Average
Asia	61.2		600,000
Africa	22.8		100,000
Europe	35.3		339,100
North America	54.0		225,000
South America	14.9		188,775

4.2 Hypothetical Automotive Company Profile

This Hypothetical Automotive Company is based on the public data collected about current automotive manufacturers. Once the Hypothetical Company is established, the tools can be used the company profile to examine what the risks and water issues are in those locations. This also serves as an opportunity to examine what the current water tools are capable of examining.

The inputs listed are the only ones input into any tool. For example, the Water Risk Filter has an entire survey with many more questions and if they are not answered by the HAC profile, they are left blank or the default values are removed. This is done to create as similar inputs as possible to be able to compare the outputs of the tools. The Water Risk Filter will have some additional analysis based on the other parts of the survey, but that will be a separate section from the main tool analysis.

4.2.1 Water Usage Differences

The "Car" and "Truck" locations have different water usages. This is both realistic and gives an opportunity to examine how the tools handle similar locations with different water usage information. Before any analysis is run, it can be reasonable to leave out an examination of Aqueduct with relation to water usage because it does not take water usage as an input (see Figure 17). Additionally, there are regional differences for the water source. These are consistent with the CDP Water Disclosure Reports from GM (GM, 2014b) and VW (VW, 2014e). The powertrain factories listed for facilities 15 and 16 are broadly consistent with existing (mapped in Figure 23) VW facilities that produce just engines and transmissions (VW, 2014b) (VW, 2014c). The UK Super Luxury Car location is a representation of the Bentley facility in the United Kingdom (Volkswagen, 2014a).

4.3 Chapter 4 Summary

Chapter 4 summarizes the collected data about water use information for a variety of automakers. The purpose of the collection is to create a representative automotive manufacturing company profile, the HAC. The realistic values are important because it would not be useful to create a company profile without having concrete water use information. With the HAC, it is now possible to run the water tools discussed in Chapter 2 and examine their results and the impacts those results could have on the HAC. For example, if the HAC were a functioning company, the facilities with the highest risk could be upgraded to recycle more water or rework their water supply.

Table 12 Hypothetical Automotive Company water profile based on publically available automotive manufacturing data

Hypothetical Automotive Company (HAC) Water Data																
						Water Values in m^3 / year							Vehicles			
Facility Name	Country	Region	Site ID	Latitude	Longtitude	Surface	Groundwater	Municipal	Total	Discharge	Recycled	Consumption	Production	Employees	m^3 Water/Production	Prod/Year/Worker
USA Car	USA	North America	1	42.5	-83.4			400,000	400,000	200,000	100,000	100,000	100,000	2,222	4.0	45.0
USA Truck	USA	North America	2	42.5	-83.4			800,000	800,000	400,000	200,000	200,000	200,000	4,444	4.0	45.0
India Car	India	Southern Asia	3	13.1	80.27	200,000			200,000	100,000	50,000	50,000	50,000	833	4.0	60.0
India Truck	India	Southern Asia	4	13.1	80.27	400,000			400,000	200,000	100,000	100,000	100,000	1,667	4.0	60.0
Germany Car	Germany	Western Europe	5	48.13	11.56			500,000	500,000	250,000	125,000	125,000	200,000	5,714	2.5	35.0
Mexico Car	Mexico	Central America	6	28.64	-106.1	200,000			200,000	100,000	50,000	50,000	50,000	1,111	4.0	45.0
China Car	China	Eastern Asia	7	29.67	106.53		200,000		200,000	100,000	50,000	50,000	50,000	833	4.0	60.0
China Truck	China	Eastern Asia	8	29.67	106.5			400,000	400,000	200,000	100,000	100,000	100,000	1,667	4.0	60.0
Japan Car	Japan	Eastern Asia	9	35.18	136.9			400,000	400,000	200,000	100,000	100,000	100,000	1,667	4.0	60.0
Japan Truck	Japan	Eastern Asia	10	35.18	136.9			800,000	800,000	400,000	200,000	200,000	200,000	3,333	4.0	60.0
South Korea Car	Korea Republic of	Eastern Asia	11	35.6	129.3			2,000,000	2,000,000	1,000,000	500,000	500,000	500,000	8,333	4.0	60.0
Brazil Car	Brazil	South America	12	-23.6	-46.6	200,000			200,000	100,000	50,000	50,000	50,000	3,333	4.0	15.0
Brazil Truck	Brazil	South America	13	-23.6	-46.6	400,000			400,000	200,000	100,000	100,000	100,000	6,667	4.0	15.0
UK Super Luxury	United Kingdom	Western Europe	14	53.099	-2.44			110,000	110,000	55,000	27,500	27,500	2,000	4,000	55.0	3.0
Germany Engine	Germany	Western Europe	15	48.13	11.56			200,000	200,000	100,000	50,000	50,000	1,000,000	2,500	0.2	400.0
Brazil Transmission	Brazil	South America	16	-23.6	-46.6			200,000	200,000	100,000	50,000	50,000	1,000,000	2,500	0.2	400.0

CHAPTER 5 GLOBAL WATER TOOL ANALYSIS OF HYPOTHETICAL AUTOMOTIVE COMPANY

5.1 Global Water Tool Overview

The GWT has many capabilities related to water analysis. Following the workflow described earlier (Figure 4); the following sections are a demonstration of what the tool is capable of doing. Inputting the HAC profile into the tool is outlined first, and then the results are examined. Additionally, there is an analysis of the difference between watershed-level data and country-level data.

It is important to note that this tool, unlike the others, is an Excel workbook and not an online tool. The version of the GWT used in this thesis is "Global Water Tool 2012.1". This is important because the same tool can be used and saved independently by the user. This means that the tool will give consistent results. There *may* be newer versions of the GWT provided by the WBCSD, but the results for this thesis are from the 2012.1 version. However, the other tools will always be using the latest datasets available, even though the results may not be consistent each time the tools are used, due to updates in the datasets or tool calculations.

5.2 Input HAC into GWT

Facility location, industry type, and water accounting information are needed as inputs for the tool to operate. The water data input into the tool exactly matches the Hypothetical Company Water Data from Table 12 in Chapter 4. That information is input into the tool directly or in the form of an input box in the GWT (Figure 25).

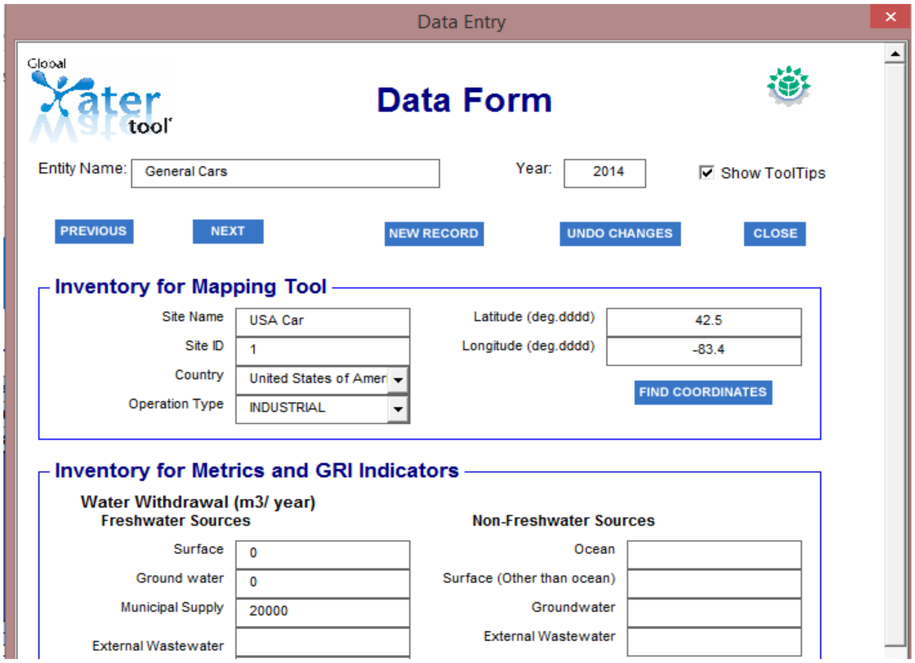


Figure 25 Data Input Form for GWT

5.3 Results for HAC from GWT

5.3.1 Output from GWT

The GWT has multiple outputs that all fall into three types: maps, metrics, or water accounting reports. The “Reporting” section of the GWT is to simply collect the water data and aggregate it into the format of some reporting groups, such as the Carbon Disclosure Project or the Global Reporting Initiative (WBCSD, 2011c). For the purposes of this thesis, investigating how to analyze water issues and their impacts by manufacturing, this function does not serve much purpose. However, for companies reporting their water usage, this capability could be very useful (WBCSD, 2011c). As noted in a variety of papers (CDP, 2014; Falkenmark et al., 1989; Mueller et al., 2014; Rijsberman, 2006) the metric that affects industrial operations the most is water stress/scarcity. Because of a lack of consistent definitions of those terms, they will be explained in detail for each tool. Additionally, the other country and watershed metrics, as well as the mapping capabilities, are useful for this investigation of the water situation of the HAC and how that can inform other companies or groups.

5.3.2 GWT Equations for Stress/Scarcity

The GWT calculates stress according to the definition of water stress as defined by Falkenmark (Falkenmark et al., 1989). This calculation is shown in Equation 1.

Equation 1 GWT Calculation of Water Stress

$$Stress\ (ARWS\ or\ TRWS) = \frac{Total\ Water\ Available}{Population\ in\ given\ region}\ [m^3/person/year]$$

The GWT also has a scarcity metric, and it is a calculation of the Total Annual Withdrawal and the Total Annual Available for a given grid of land (given by a 30 minute x 30 minute latitude by longitude resolution) (WBCSD, 2011b).

Equation 2 GWT Calculation of Water Scarcity

$$Scarcity = \frac{Total\ Annual\ Withdrawal}{Total\ Annual\ Available}\ [ratio]$$

5.4 Country Reports from GWT

5.4.1 Overall Country Results

Country Reports group the facilities by country and combines their water usage. The results are then reorganized by individual metrics and the mapping functions. On the Output Country tab in the workbook, the values of individual metrics from designated databases are listed. For example, the Annual Renewable Water Supply per Person Projection raw values are available. The water usage is combined for each country. For example, in Figure 26 the values for all of the facilities in Brazil are used in the overall calculation. All of the figures that follow are based on the Hypothetical Company water input, unless otherwise noted.

			Total Renewable per person (actual) (TRWR/person) (2008) (m^3/person/yr)	Total Renewable per person (actual) (TRWR/person) (2025) (m^3/person/yr)	Total Renewable per person (actual) (TRWR/person) (2050) (m^3/person/yr)
Americas					
	Brazil		42,886.00	38,507.59	37,677.56
		Brazil Car			
		Brazil Transmission			
		Brazil Truck			

Figure 26 GWT Raw Value of Annual Renewable Water Supply Projection

This is a useful feature because it can quickly give the user an overview of the water supply in a given country generally. However, the drawback is that the facilities could be experiencing different water situations in different locations in the country.

For the country level Renewable Water metric, no countries HAC facilities are experiencing more than a 'stressed' situation as shown Figure 27. This figure indicates there are three facilities in countries where the total renewable water per person has fallen into a stressed state, which is defined as at or below 1700 m^3/person/year (Falkenmark et al., 1989). If the value had been above 1700 m^3/person/year then it would not be listed in a stressed state. Additionally, there is a projection of the renewable water supply per person from FAO for the year 2025 shown in Figure 28. This projection will be shown for individual facilities later, but it important to note that these two figures (Figure 27 and Figure 28) allow the user to quickly understand the entire company's stress profile for Country Renewable Water supply and a projection of that metric to 2025.

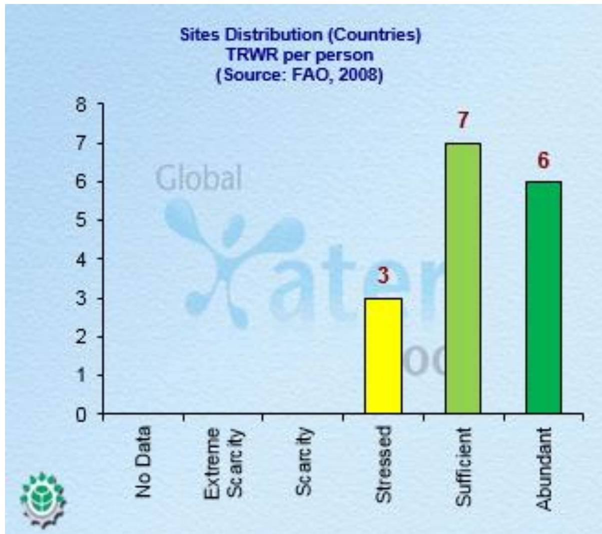


Figure 27 FAO Renewable Water per Person by Country Average Values

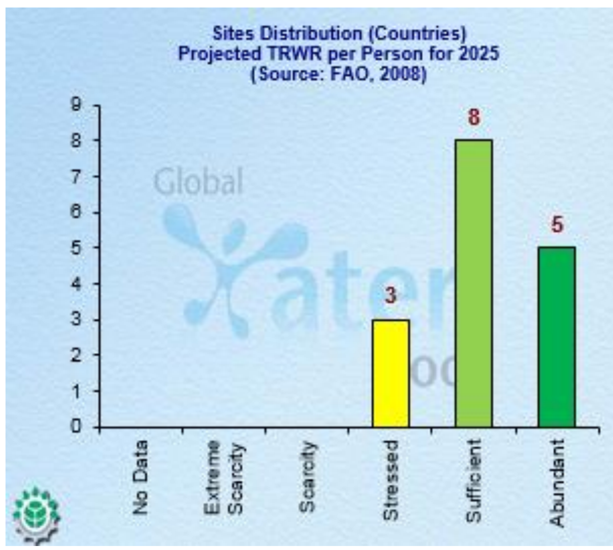


Figure 28 FAO Renewable Water per Person by Country Average Values Projection for 2025

5.4.2 Individual Facility Results

The GWT outputs the country results in a large table with facilities grouped by country. Table 13 shows all of the outputs from the country report. Most come from the AquaStat database, but the UN Population Division and the WHO/UNICEF databases contribute as well. These databases give very interesting water metrics, such as Population served with improved sanitation, Agricultural water withdrawal as a part of total, and Desalinated water produced. The FAO

AquaStat database has Total Renewable water and Internal Renewable water values. The distinction between those types of water is the Internal Renewable is the average flow from precipitation, and the Total Renewable is a measure of the total water available per inhabitant (WBCSD, 2011b). Other metrics from the GWT country output are potentially useful, such as the Industrial Water Withdrawal as part of the total water withdrawn (%). For example, for the countries investigated in Europe, UK and Germany, the percentage is very high, 75.4% and 67.9% respectively, whereas in India that number is very low at 5.5%.

Other metrics are also indicators of the water infrastructure, such as the WHO/UNICEF values for Population Served with Improved Water or Sanitation. However, for the purpose of this thesis, the main country-level metric is the Total Renewable per Person per year. It is a measure of m^3/person/year and follows the work by Falkenmark defining location's stress levels (Falkenmark et al., 1989). Because this metric has similar units to the watershed level metric in the GWT (as well as metrics from Aqueduct and the Water Risk Filter) and is the standard calculation for water stress levels, it will be examined further. It will also be the metric most used to compare the results of all the tools.

The "Total Renewable Water Supply per Person" (TRWR) value corresponds with a water stress state. The value from a database is assigned to a facility input into the tool based on its location. From that value, a corresponding stress state is given based on the ranges shown in Table 14. These values are ingrained in the GWT, and the same values are consistent between tools and different databases (Falkenmark et al., 1989).

Table 13 GWT Country Level Outputs for HAC

Region	Country	Site Name	Operation Type	Water Inventory: Total Freshwater Consumption (m³/year)	Water Inventory: Total Water Consumption (m³/year)
Americas			**Total (Region)**	1,100,000	1,100,000
	Brazil		***Total (Country)***	400,000	400,000
		Brazil Car	INDUSTRIAL	100,000	100,000
		Brazil Transmission	INDUSTRIAL	100,000	100,000
		Brazil Truck	INDUSTRIAL	200,000	200,000
	Mexico		***Total (Country)***	100,000	100,000
		Mexico Car	INDUSTRIAL	100,000	100,000
	United States of America		***Total (Country)***	600,000	600,000
		USA Car	INDUSTRIAL	200,000	200,000
		USA Truck	INDUSTRIAL	400,000	400,000
Asia			**Total (Region)**	2,200,000	2,200,000
	China		***Total (Country)***	300,000	300,000
		China Car	INDUSTRIAL	100,000	100,000
		China Truck	INDUSTRIAL	200,000	200,000
	India		***Total (Country)***	300,000	300,000
		India Car	INDUSTRIAL	100,000	100,000
		India Truck	INDUSTRIAL	200,000	200,000
	Japan		***Total (Country)***	600,000	600,000
		Japan Car	INDUSTRIAL	200,000	200,000
		Japan Truck	INDUSTRIAL	400,000	400,000
	Korea Republic of		***Total (Country)***	1,000,000	1,000,000
		South Korea Car	INDUSTRIAL	1,000,000	1,000,000
Europe			**Total (Region)**	405,000	405,000
	Germany		***Total (Country)***	350,000	350,000
		Germany Car	INDUSTRIAL	250,000	250,000
		Germany Engine	INDUSTRIAL	100,000	100,000
	United Kingdom of Great Britain		***Total (Country)***	55,000	55,000
		UK Super Luxury	INDUSTRIAL	55,000	55,000
			Total (All Operations Types)	**3,705,000**	**3,705,000**
			Total (Office/Retail)	**0**	**0**
			Total (Industrial)	**3,705,000**	**3,705,000**
			Total (Suppliers)	**0**	**0**

Country	FAO AQUASTAT																WHO/UNICEF (2008)									UN Pop. Div.
	Total Internal Renewable (IRWR) (2006) (10^9 m³/yr)	Total Internal Renewable per person (IRWR/person) (2008) (m³/person/yr)	Total External (actual) (ERWR) (2006) (10^9 m³/yr)	Total Renewable (actual) (TRWR) (2006) (10^9 m3/yr)	Total Renewable per person (actual) (TRWR/person) (2008) (m³/person/yr)	Total Renewable per person (actual) (TRWR/person) (2025) (m³/person/yr)	Total Renewable per person (actual) (TRWR/person) (2050) (m³/person/yr)	Dependency Ratio (2006) (%)	Agricultural water withdrawal as part of total (Around 2002) (%)	Municipal water withdrawal as part of total (Around 2002) (%)	Industrial water withdrawal as part of total (Around 2002) (%)	Total water withdrawal: per person (Around 2002) (m³/person/yr)	Total freshwater withdrawal (surface + gw) (10^9 m3/yr)	Total freshwater withdrawal as % of TRWR (Around 2002) (%)	Desalinated water produced (2005) (10^9 m³/yr)	Population Total (number)	Population Urban (%)	Population Rural (%)	Population served with improved water (%): Total Coverage	Population served with improved water (%): Urban Coverage	Population served with improved water (%): Rural Coverage	Population served with improved sanitation (%): Total Coverage	Population served with improved sanitation (%): Urban Coverage	Population served with improved sanitation (%): Rural Coverage	Urban Annual Growth Rate (2010-2015) (%)
Brazil	5418	28,223.00	2,815.00	8233	42,886.00	38,507.59	37,677.56	34.19	61.8%	20.3%	18.0%	330.83	59.30	0.72	No Data	191,971,510	86	14	97	99	84	80	87	37	1.14
Mexico	409	3,768.00	48.22	457.222	4,212.00	3,706.05	3,545.18	10.55	77.1%	17.4%	5.5%	768.87	78.22	17.04	0.02	108,555,490	77	23	94	96	87	85	90	68	1.23
United States of America	2800	8,984.00	251.00	3051	9,789.00	8,504.89	7,553.25	8.23	41.3%	12.7%	46.0%	1,648.00	479.29	15.65	0.58	311,666,000	82	18	99	100	94	100	100	99	1.23
China	2812.4	2,092.00	17.17	2829.569	2,104.00	1,936.09	1,984.21	0.61	67.7%	6.6%	25.7%	486.45	630.29	21.80	No Data	1,337,411,170	43	57	89	98	82	55	58	52	2.29
India	1260.54	1,067.00	636.12	1896.66	1,591.00	1,313.52	1,164.95	33.93	86.5%	8.1%	5.5%	596.95	645.84	34.05	0.00	1,181,411,910	29	71	88	96	84	31	54	21	2.38
Japan	430	3,378.00	No Data	430	3,378.00	3,559.81	4,229.83	No Data	62.5%	19.7%	17.9%	693.66	88.43	20.37	0.04	127,293,090	66	34	100	100	100	100	100	100	0.15
Korea Republic of	64.85	1,347.00	4.85	69.7	1,447.00	1,408.54	1,581.32	6.96	48.0%	35.6%	16.4%	393.18	18.59	26.67	0.00	48,152,300	81	19	98	100	88	100	100	100	0.61
Germany	107	1,301.00	47.00	154	1,872.00	1,943.02	2,184.27	30.52	19.8%	12.3%	67.9%	570.41	47.05	30.55	No Data	82,264,270	74	26	100	100	100	100	100	100	0.03
United Kingdom of Great Britain	145	2,359.00	2.00	147	2,392.00	2,199.51	2,025.21	1.36	2.9%	21.7%	75.4%	160.64	9.54	6.47	0.03	61,230,910	90	10	100	100	100	100	100	100	0.72

Table 14 shows the standardized Falkenmark water stress ranges used by the GWT and is consistent across tools and studies (Falkenmark et al., 1989; WBCSD, 2011b).

Standard Water Stress Ranges	
> 4,000	Abundant
1,700 - 4,000	Sufficient
1,000 - 1,700	Stress
500 - 1,000	Scarcity
< 500	Extreme Scarcity

The consistency of the stress state for the metrics is useful because the state is what is important for a company, not the actual value of the metric. It allows different databases and water analysis tools to give the same type of output so that users can consistently understand results. This also allows direct comparisons to be made, which will be covered later in this thesis.

As expected, the Country Level Output gives the same value for all the facilities in a country. The GWT Map of the HAC with a country-level water stress is shown in Figure 29.

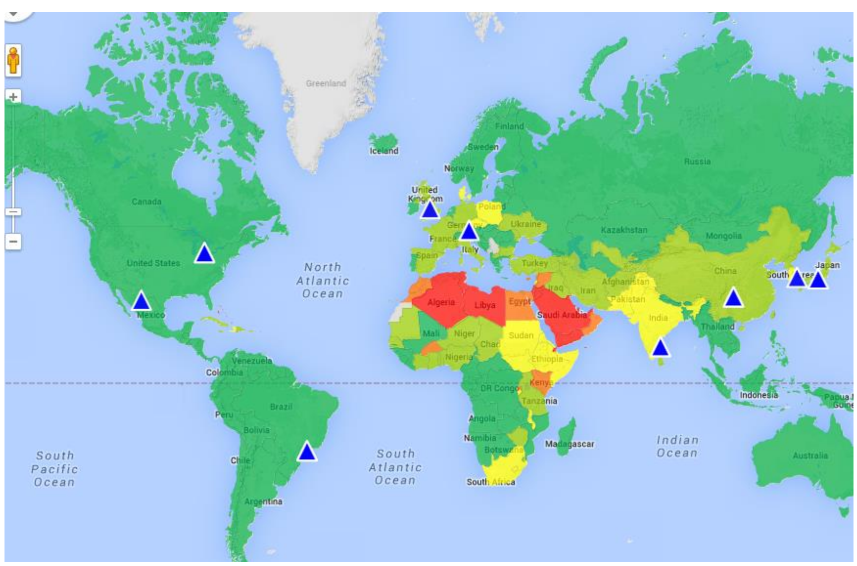


Figure 29 GWT Renewable Water per Person 2008 Map with HAC Facilities

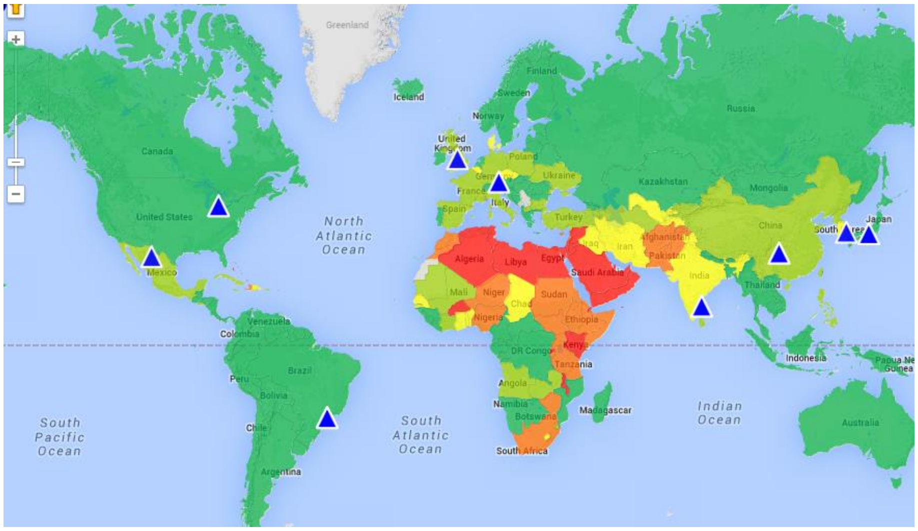


Figure 30 GWT Renewable Water per Person Projection for 2050 Map with HAC Facilities

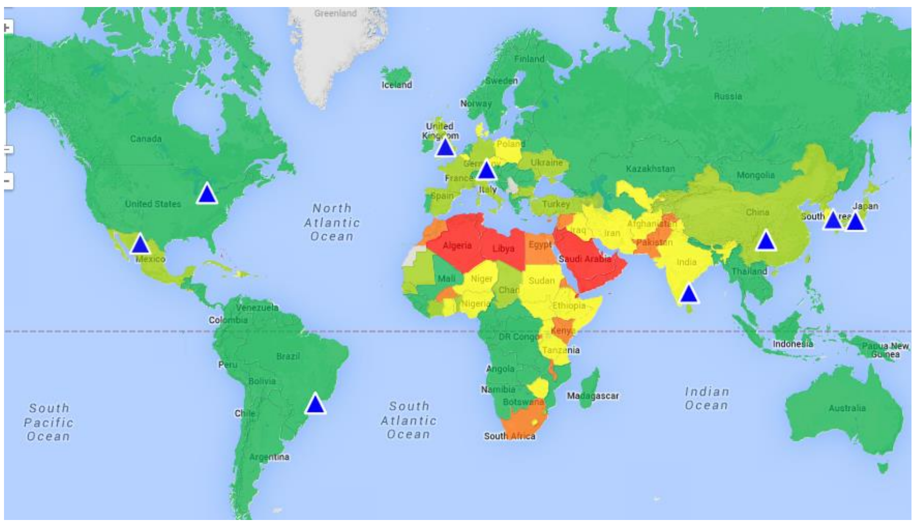


Figure 31 GWT Renewable Water per Person Projection for 2025 Map with HAC Facilities

The GWT also gives a projection of the estimates water stress for 2025 and 2050. These projections do not take into account climate change, and are primarily based on population estimates (WBCSD, 2011b) and are shown in Figure 30 and Figure 31. Though these projections do not include climate change influences, they still show the water stress level increasing or staying at the same level for each country. Table 15 shows the Total Renewable per Person for each country that has a facility in HAC. One key concept to note is that the exact value of total or projected renewable water does not determine the water stress state. What determines the water stress state it is which range it falls in based on the Falkenmark index categories shown in Table 14. For example, the country of Brazil is listed as having 42,886 m^3/person/year, yet it is listed as having the same water stress state as the Mexico at 4,212 m^3/person/year (abundant).

The GWT Country Reports groups the facilities by country and combines their water usage. This can give the user an idea of the current water stress state and projections for future stress. However, the main issue with country averages is that it is not detailing the water stress for each facility specifically. For example, with this database, it is impossible to determine a difference between two locations in the same country for any water metric. Despite this issue, the Total Renewable per person metric can be used to estimate the stress, and will be compared with the water stress values from other tools and databases.

Table 15 Country Renewable Water Supply per Person results for HAC from GWT

			Total Renewable per person (actual) (TRWR/person) (2008) (m^3/person/yr)	Total Renewable per person (actual) (TRWR/person) (2025) (m^3/person/yr)	Total Renewable per person (actual) (TRWR/person) (2050) (m^3/person/yr)
Americas					
	Brazil		42,886.00	38,507.59	37,677.56
		Brazil Car			
		Brazil Transmission			
		Brazil Truck			
	Mexico		4,212.00	3,706.05	3,545.18
		Mexico Car			
	United States of America		9,789.00	8,504.89	7,553.25
		USA Car			
		USA Truck			
Asia					
	China		2,104.00	1,936.09	1,984.21
		China Car			
		China Truck			
	India		1,591.00	1,313.52	1,164.95
		India Car			
		India Truck			

For context, (based on the ideas summed in Figure 1) if the country-level reports from GWT were reported to the HAC executives', the notable facilities would only be the ones listed as being "Stressed" with their water supply being below 1700 m^3/person/year. However, the values for the water supply were relatively close to that number, so the mitigation of the risk may be as simple as ensuring the local infrastructure can handle the supply to the facility. The country-level report for the HAC presents a situation of a few facilities that are concerning, but overall most of the facilities are in a 'Sufficient' or 'Abundant' water stress state. The only stress metric listed three facilities as a potential for supply problems, and the rest of the metrics were not cause for concern.

5.5 Watershed Reports from GWT

The GWT also has a collection of water metrics based on watershed level data. The difference between country-level and watershed-level is that the country-level data is an average (typically) of the water metric inside that country, and the watershed-level metrics are the values in that watershed in a particular location (typically based on GPS coordinates). The watershed output from the GWT is not as extensive as the country output. For facility information, it is limited to Annual Renewable Water Supply per person (ARWS) and a projection for 2025 from the World Resource Institute, Mean Annual Relative Water Stress Index (MAR) from the University of New Hampshire, and if Conservation International lists a given location as a bio-diversity hotspot. There are additional mapping results that do not have values specifically broken down for the facilities. The metrics that are mapped but not given as raw values are Environmental Water Scarcity Index by Basin (EWS) and Areas of physical and economic water scarcity (AS). Despite the relatively limited number of metrics, the increased resolution and mapping capabilities can provide insight to the HAC water situation.

The Annual Renewable Water Supply (ARWS) per person metric follows the same rules as the Total Renewable per person metric from the country report. The metric follows the Falkenmark indicator for stress levels (Table 14) and will be compared with the country-level results later in this chapter of the thesis. The projection of ARWS is based on population, and does not take into account any infrastructure or climate change scenarios. Both the water stress state and projection databases are produced by the World Resources Institute (WBCSD, 2011b).

The University of New Hampshire (UNH) Mean Annual Relative Water Stress Index (MAR) is a unique water metric. According to the GWT FAQ, “A ratio of 0.4 or greater indicates conditions of water stress, and one that is more than likely over-tapping the resources needed to sustain a functioning freshwater ecosystem. A level of more than 1 is hyper-stressed.” (WBCSD, 2011c). It is essentially a measure of the ratio of water use to the renewable water available. The database also has a much higher resolution than most water metrics, 30 minute x 30 minute (latitude and longitude).

The International Water Management Institute (IWMI) is a NGO research organization that investigates water and land management issue in developing countries. For the GWT, there two metrics from IWMI are mapped, although the individual facility results are not given explicitly. The Environmental Water Scarcity Index by Basin (EWS) is similar in principal to the MAR metric in that is a ratio of use to the available renewable water. However, it is calculated for a given water basin and not for a specific GPS location. The other metric tracked by IWMI is Areas of physical and economic water scarcity (PES). This metric takes into account human, institutional, and financial influences in water availability. The results are broken down into four categories: 1) Little or No Scarcity 2) Approaching Physical Scarcity 3) Physical Scarcity 4) Economic Scarcity (WBCSD, 2011b).

5.5.1 Overall Watershed Results

The overall HAC results are presented in a similar manner as the country-level results. Figure 32 shows that according to the ARWS metric, there are three HAC facilities in ‘Extreme Scarcity’ and one in ‘Scarcity’. Figure 27 from the country-level report showed no facilities in either ‘Extreme Scarcity’ or ‘Scarcity’. The Falkenmark index defines any per capita water supply below 1700 m^3/person/year as a situation in which disruptive shortages of water can occur. Having a value for ARWS below 500 m^3/person/year for three facilities is cause for concern for the general operation of the HAC. The other facility that is in a “Scarcity” water stress state is cause for concern as well. The projection from WRI of the ARWS for 2025 shows no change in terms of the state of water supply for any of the locations Figure 33.

Figure 32 Watershed-Level Combined ARWS by Falkenmark Index

Figure 33 Watershed-Level Combined ARWS Projection by Falkenmark Index

The projection is useful to observe to estimate the future water stress, but the GWT's watershed-level water stress profile is significantly direr than the country-level water stress profile

(Figure 29). The difference is drastic between the country-level and watershed-level Falkenmark stress states.

The MAR index from UNH shows another overall company profile (Figure 34) with only one facility in a scarcity condition and the rest of the facilities in low scarcity conditions.

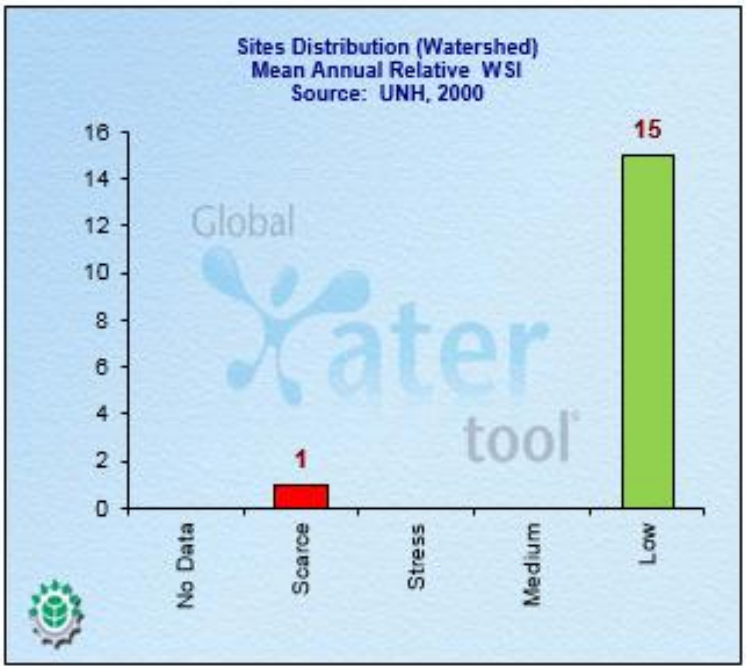


Figure 34 Watershed-Level Combined MAR HAC Profile

Finally, CI groups the facilities by their status as being in a location of a biodiversity hotspot. This may be an important metric for environmental concerns, but it will most likely not affect the operations of a facility, barring an intervention of some kind from a restriction of industry to protect the hotspot.

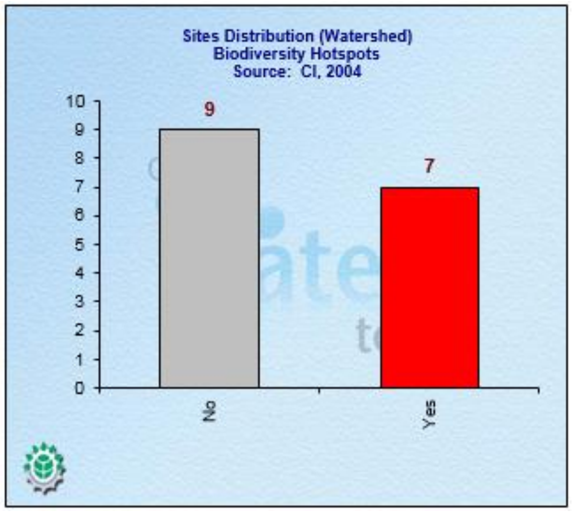


Figure 35 CI Biodiversity Hotspot Profile

The watershed-level m^3/person/year value for renewable water map shows the level of detail that is offered by the GWT. Figure 36, Figure 40, and Figure 41 show the UNH Relative Water Stress Index (MAR), Annual Renewable Water Supply per person (ARWS), and a projection of ARWS for 2025, respectively.

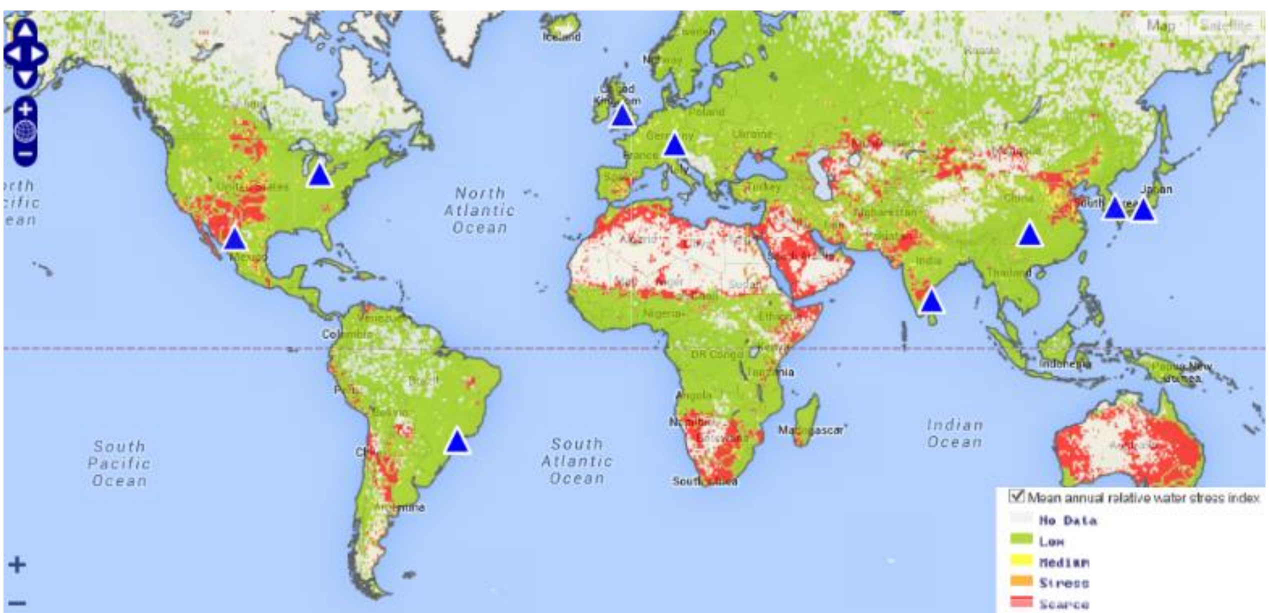


Figure 36 Map of MAR for the HAC Facilities

The important difference for the watershed metrics is their level of detail compared with the country level metrics. For example, the HAC Facility in Mexico is listed as being in a state of "Scarcity" according to the watershed-level Falkenmark renewable water indicator, but the facility is listed as "Abundant" by the country-level Falkenmark indicator for renewable water. Mapping the metrics (Figure 29 and Figure 40) show the difference between the two.

The PES map Figure 37 (which is the only way the metric is available in the GWT) shows watershed divided into one of four categories as described in the previous section. This metric could potentially help a company estimate what types of issues may arise in different regions. The EWS map (Figure 38) works very similarly to the MAR metric, although the ratio is reversed in this case, with larger values corresponding with more dire water scarcity. Finally, the GWT can also map the Biodiversity Hotspots shown in Figure 39.

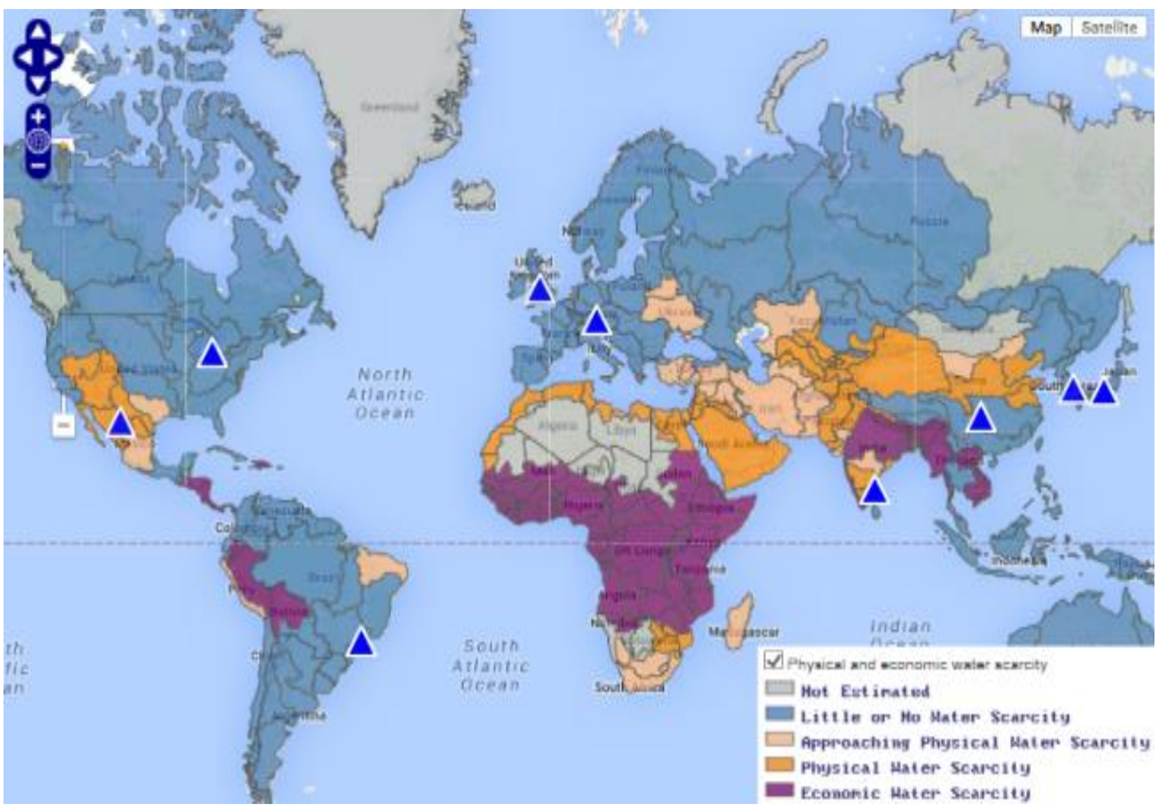


Figure 37 Map of PES for the HAC Facilities

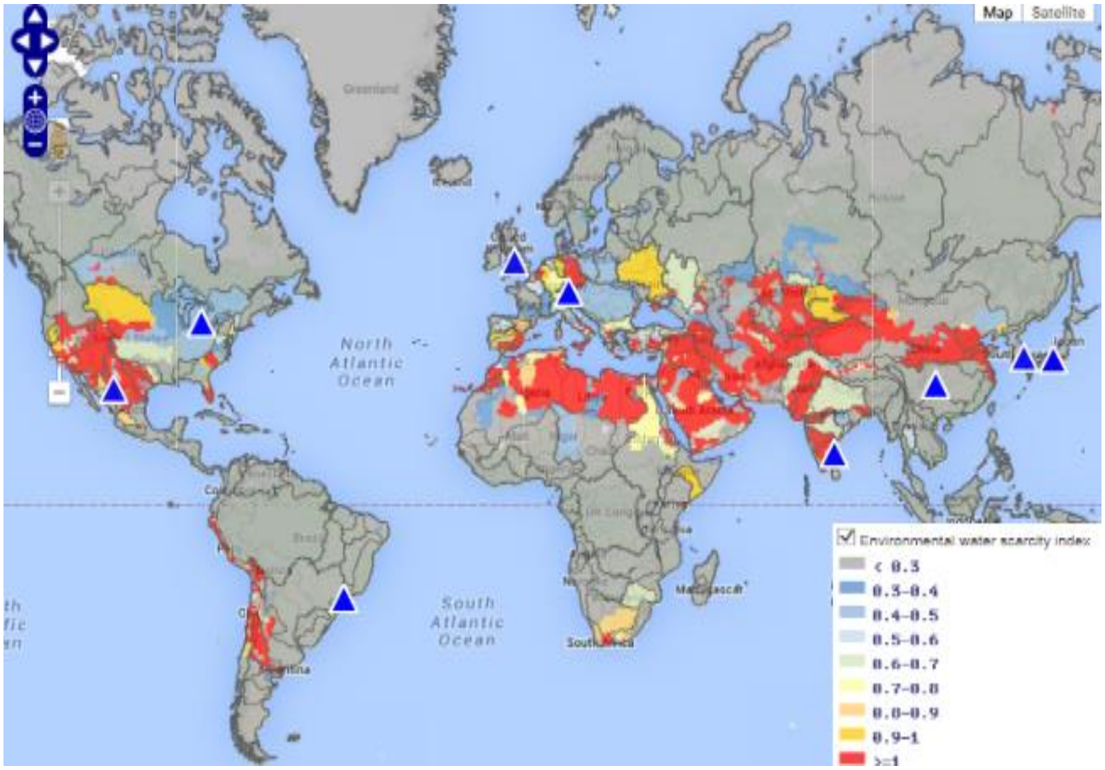


Figure 38 Map of EWS for the HAC Facilities

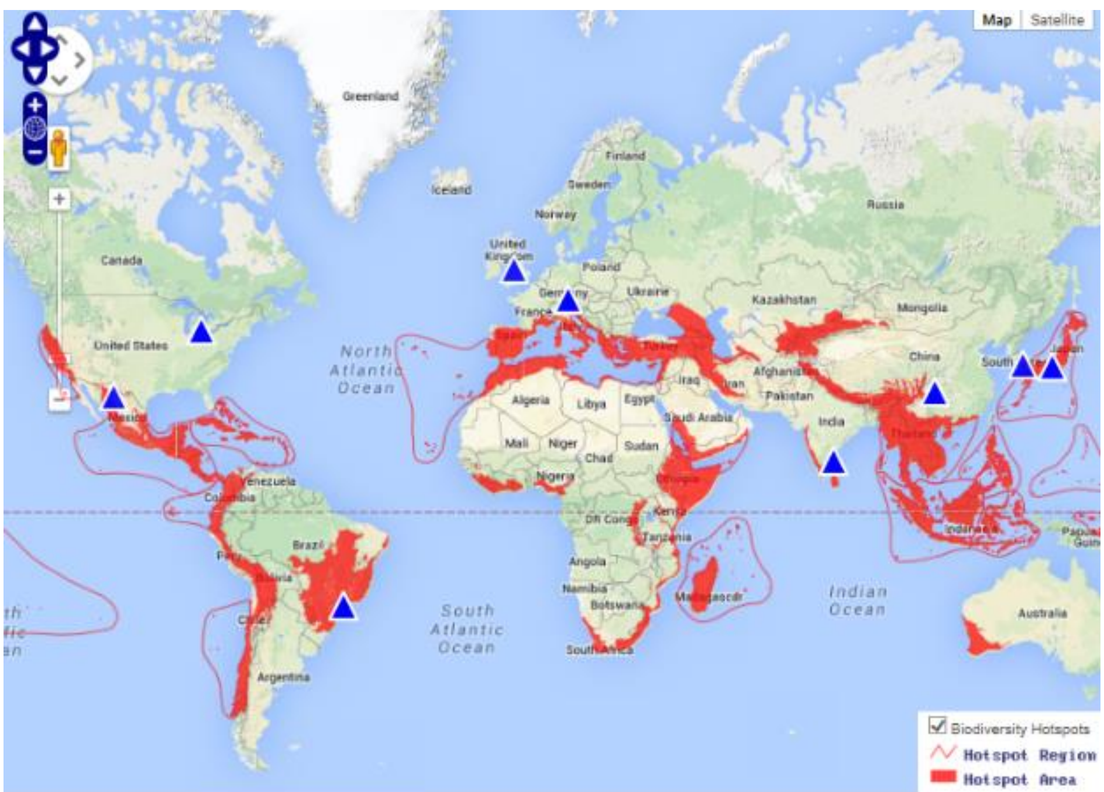


Figure 39 Map CI Biodiversity Hotspots with HAC Facilities

These overall results from the GWT can provide insight, but there is a significant amount of disagreement on the general stress state of the profile. If the HAC followed the MAR metric, only one facility would be listed as problematic. If the HAC primarily concerned themselves with the ARWS, then four facilities are in stress states that are cause for concern because of the risk of disruption of operations. This is shown in Table 16, with the MAR and ARWS having practically no alignment. This is due for two main reasons: First, the metrics are calculated differently, one uses the Falkenmark Index and the other is a ratio. Second, the databases are from different years, 1995 for ARWS (WBCSD, 2011b) and 2000 for MAR (WBCSD, 2011b). The additional mapping functions can provide insight for different geographic regions' water situation, but are harder to use because of the lack of facility level information. Finally, the CI Biodiversity Hotspot metric may be useful for other applications, but whether or not a facility is in a biodiversity hotspot likely does not pose a risk to operations. A more detailed biological-based risk analysis may provide more insight on the impacts of endangered species; however the GWT provides a starting point for this type of analysis (WBCSD, 2011a). The overall agreement and impacts of the GWT Watershed Report will be covered in the following sections.

Table 16 GWT Results for HAC of ARWS and MAR

Facility	**WRI** Annual Renewable Water Supply per Person (1995) **ARWS** (m3/person/year)	**UNH** Mean Annual Relative Water Stress Index (2000) **MAR** (unitless)
USA Car	> 4,000	< 0.2
USA Truck	> 4,000	< 0.2
India Car	< 500	< 0.2
India Truck	< 500	< 0.2
Germany Car	1,700 - 4,000	< 0.2
Mexico Car	500 - 1,000	> 1
China Car	1,700 - 4,000	< 0.2
China Truck	1,700 - 4,000	< 0.2
Japan Car	> 4,000	< 0.2
Japan Truck	> 4,000	< 0.2
South Korea Car	1,700 - 4,000	< 0.2
Brazil Car	> 4,000	< 0.2
Brazil Truck	> 4,000	< 0.2
UK Super Luxury	< 500	< 0.2
Germany Engine	1,700 - 4,000	< 0.2
Brazil Transmission	> 4,000	< 0.2

ARWS State Key

- No Data
- Extreme Scarcity
- Scarcity
- Stress
- Sufficient
- Abundant

MAR State Key

- No Data
- Low
- Medium
- Stress
- Scarce

5.5.2 Individual Facility Results

The individual facility results are essentially a table with the WRI, UNH, and CI metrics for each facility. This means that for any facility, the raw values of ARWS, the projection of ARWS for 2025, MAR Index, and whether or not the facility is in a Biodiversity Hotspot are available in the workbook.

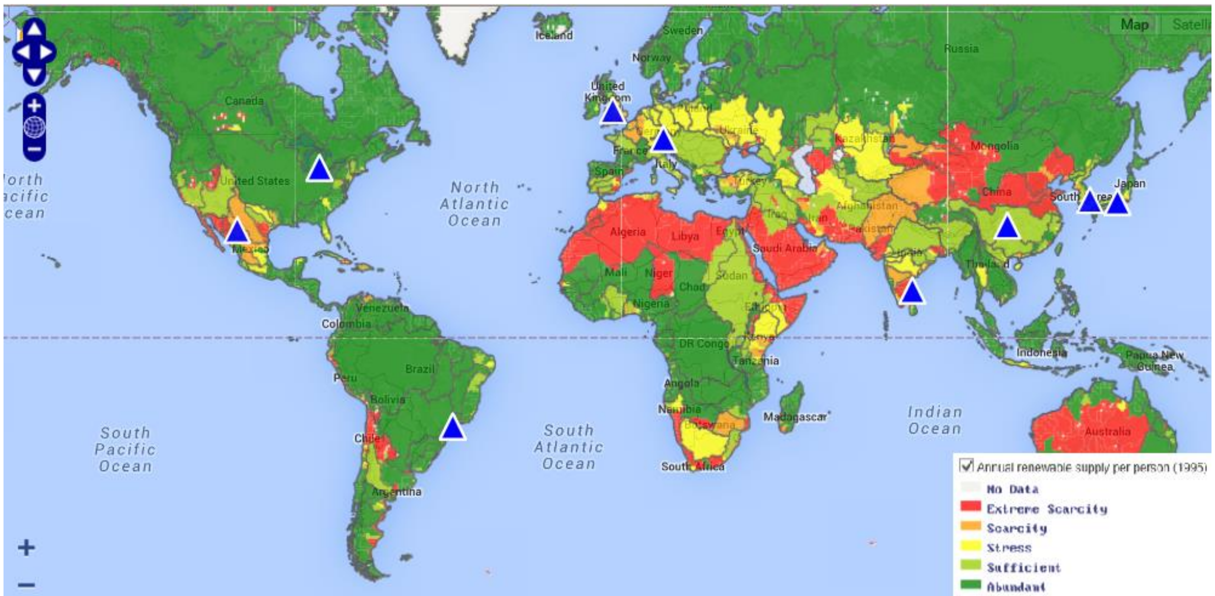


Figure 40 Map of ARWS for the HAC Facilities

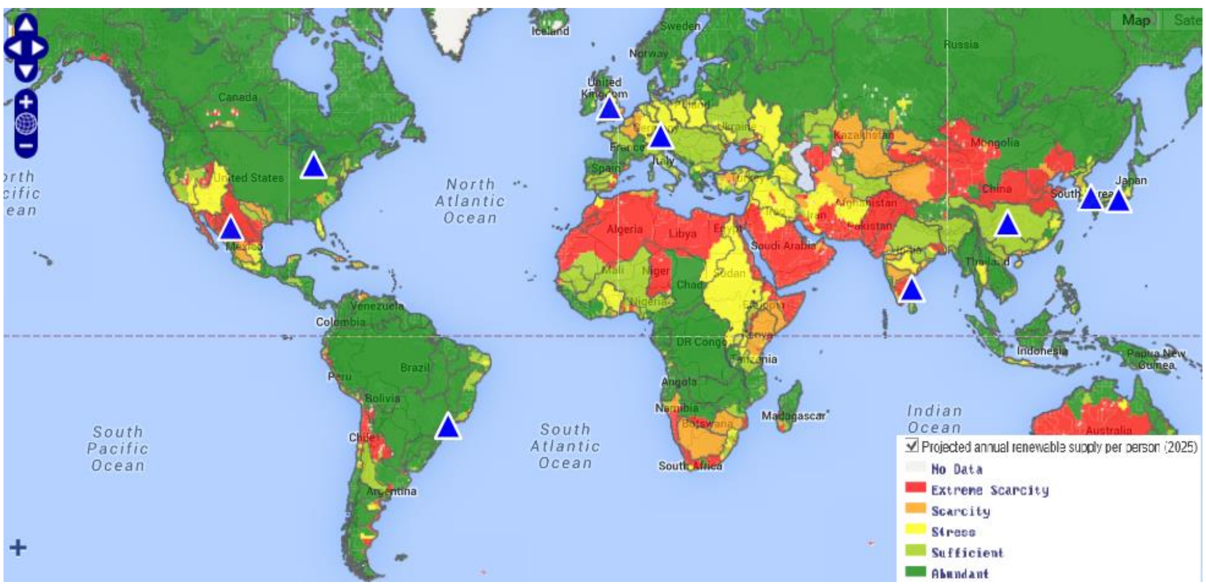


Figure 41 Map of Projection of ARWS for the HAC Facilities

The raw values shown in Table 17 give the user an immediate understanding of the water situation at each facility in terms of the water stress according to those four metrics. The projection of the Annual Renewable Water supply per person is based on population only, but it serves as an estimate for the metric in the future (WBCSD, 2011b). For example, the Mexico Car facility is projected to move from a "Scarcity" stress state to an "Extreme Scarcity." This change indicates that the water situation for that facility could seriously impact that facilities operations (Joost Schornagela, 2012). However, the UK Super Luxury facility is projected to move from "Extreme Scarcity" to "Scarcity." This means the tool is projecting that the water state of the facility will likely become better. This table essentially gives the individual facility breakdown of the overall and mapping results shown previously.

Table 17 Watershed Results for the HAC from GWT

Site Name	WRI		UNH	Conservation International
	Annual Renewable Water Supply per Person (1995) (m^3/person/year)	Annual Renewable Water Supply per Person (Projections for 2025) (m^3/person/year)	Mean Annual Relative Water Stress Index (2000) (unitless)	Biodiversity Hotspot
USA Car	> 4,000	> 4,000	< 0.2	NO
USA Truck	> 4,000	> 4,000	< 0.2	NO
India Car	< 500	< 500	< 0.2	NO
India Truck	< 500	< 500	< 0.2	NO
Germany Car	1,700 - 4,000	1,700 - 4,000	< 0.2	NO
Mexico Car	500 - 1,000	< 500	> 1	Madrean Pine-Oak Woodlands
China Car	1,700 - 4,000	1,700 - 4,000	< 0.2	NO
China Truck	1,700 - 4,000	1,700 - 4,000	< 0.2	NO
Japan Car	> 4,000	> 4,000	< 0.2	Japan
Japan Truck	> 4,000	> 4,000	< 0.2	Japan
South Korea Car	1,700 - 4,000	1,700 - 4,000	< 0.2	Japan
Brazil Car	> 4,000	> 4,000	< 0.2	Atlantic Forest
Brazil Truck	> 4,000	> 4,000	< 0.2	Atlantic Forest
UK Super Luxury	< 500	500 - 1,000	< 0.2	NO
Germany Engine	1,700 - 4,000	1,700 - 4,000	< 0.2	NO
Brazil Transmission	> 4,000	> 4,000	< 0.2	Atlantic Forest

5.6 Correlation Between Country and Watershed Outputs

The ARWS per person falls into the same category of analysis as the Total renewable per person metric from the Country Report. According to the WBSCD, "Conceptually the two variables are the same, but the input data to calculate water supply is different: The Annual Renewable Water Supply per Person uses average runoff instead of FAO country data to estimate water supply." (WBCSD, 2011c) The values of watershed ARWS will be compared to the Country Report numbers for and checked for correlation. The formula for calculating the coefficient of correlation comes from *Measurement and Data Analysis for Engineering and Science* by Dunn (Dunn, 2005).

Equation 3 Coefficient of Correlation

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

The water supply per person values are given as direct numbers for the country results, but grouped into ranges for the stress. For example, Brazil is given a rating of 42,886 m3/person/year by the TRWR country metric, but that is simply rated as >4000 for a stress state of 'Abundant' by the Falkenmark index. The watershed results are grouped into ranges and the exact value is not known. The results are organized into stress states based on ranges shown in Table 14. In order to perform the basic correlation calculation (Equation 3), the ranges are rescored into numbers 1-5, shown in Table 19.

Table 18 shows the range values of watershed (ARWS) and country renewable water per person (TRWR) from GWT.

Site Name	Watershed: Annual Renewable Water Supply per Person (1995)	Country: Total Renewable per person (actual) (TRWR/person) (2008)
	(m3/person/year)	(m3/person/yr)
USA Car	> 4,000	> 4,000
USA Truck	> 4,000	> 4,000
India Car	< 500	1,000 - 1,700
India Truck	< 500	1,000 - 1,700
Germany Car	1,700 - 4,000	1,700 - 4,000
Mexico Car	500 - 1,000	> 4,000
China Car	1,700 - 4,000	1,700 - 4,000
China Truck	1,700 - 4,000	1,700 - 4,000
Japan Car	> 4,000	1,700 - 4,000
Japan Truck	> 4,000	1,700 - 4,000
South Korea Car	1,700 - 4,000	1,000 - 1,700
Brazil Car	> 4,000	> 4,000
Brazil Truck	> 4,000	> 4,000
UK Super Luxury	< 500	1,700 - 4,000
Germany Engine	1,700 - 4,000	1,700 - 4,000
Brazil Transmission	> 4,000	> 4,000

Table 19 shows the regrouped water supply values and the correlation coefficient.

Site Name	Watershed: Annual Renewable Water Supply per Person (1995)	Country: Total Renewable per person (actual) (TRWR/person) (2008)
	(m3/person/year)	(m3/person/yr)
USA Car	1	1
USA Truck	1	1
India Car	5	3
India Truck	5	3
Germany Car	2	2
Mexico Car	4	1
China Car	2	2
China Truck	2	2
Japan Car	1	2
Japan Truck	1	2
South Korea Car	2	3
Brazil Car	1	1
Brazil Truck	1	1
UK Super Luxury	5	2
Germany Engine	2	2
Brazil Transmission	1	1
Correlation coeff.	r	0.552

The correlation calculation represents the state of the water supply for each facility based on the Falkenmark index, which is what determines if the facility is at risk for a disruption. If the reported value of renewable water for a given location is 1 or 499 its state is still listed as extremely stressed. The correlation calculation is calculating how related the listed states are, not necessarily the exact value of the metric (which is not available for watershed water supply).

The value of the correlation coefficient is .552. For most datasets, this value would correspond with moderate data agreement. However, these sets do not align very well given that they come from the same source and represent the same stress-states. That may seem obvious from the results, but to have a statistical method is valuable to quantify the agreement. Figure 42 is a reorganization of the water stress states to graphically show the discrepancies, seen in Figure 42, with 7 of the 16 facilities being given different stress states by the two measures of stress (as defined by the Falkenmark index) within the GWT. Nine facilities results agree, but some of the differences in the stress state from watershed to country are extreme. For example, the facilities in Mexico and the UK are listed as being in ‘Scarcity’ or worse according to the ARWS watershed stress, but are listed as at least ‘Sufficient’ by the country-level TRWS.

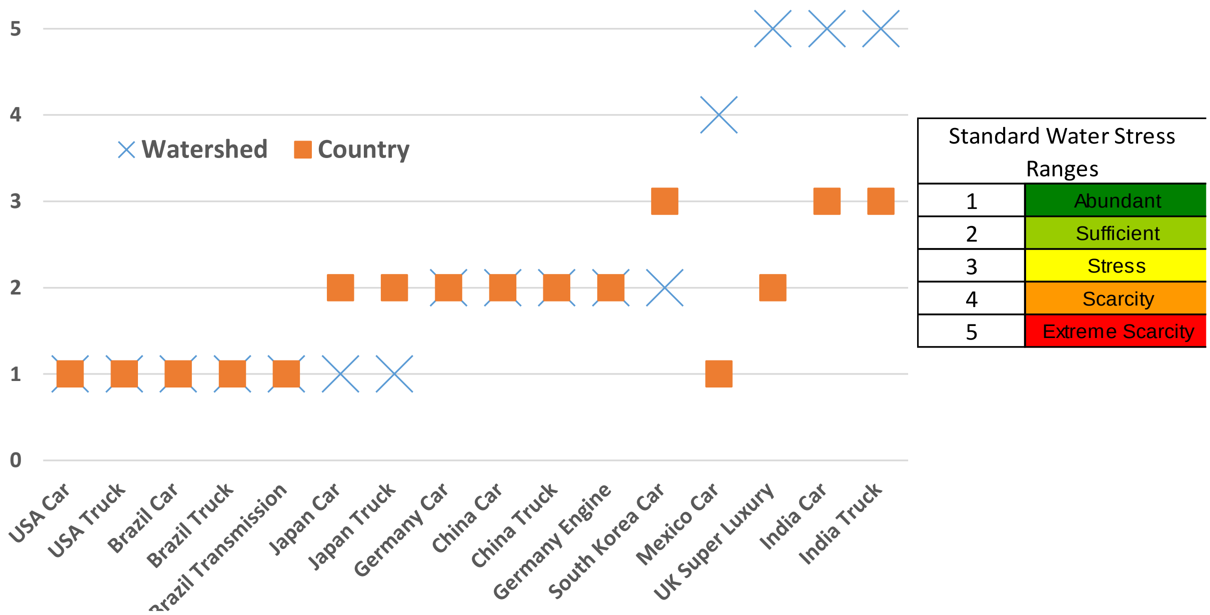


Figure 42 GWT Watershed (ARWS) and Country Water Stress Values (TRWS) for the HAC Facilities

5.7 GWT Conflicting Projection Within the Tool

Conflicting Renewable Water Stress State and Projection

Figure 43 does show one facility in one country moving from an ‘abundant’ renewable water supply to a ‘sufficient’ water supply (Mexico Car), but Figure 43 projects a much different water situation than Figure 41 which was a projection from WRI based on data from 1995 (WBCSD, 2011b). This shows one problem that arises when companies or other organizations try to get a handle on their overall water situation. Even using the same tool, there are two different projections on what may happen because the ARWS is based on watershed level data, and the TRWR is based on country-level data. Additionally, the databases for the tools are based on data collected in different years. The ARWS is from 1995 (WBCSD, 2011b) and the TRWR is from 2008 (WBCSD, 2011b). Although it is difficult to know the exact cause of the discrepancy, both likely contributed to the discrepancy.

This issue will continue when the other tools results are compared to the GWT directly. So how does the user of this tool begin to interpret these results? The main idea of how to handle this is to get a firm grasp on exactly what water metrics are important to consider, to learn how they are or should be calculated, to understand what data will be used in those calculations, and understand how that can affect both the environment and the groups operating facilities that require water.

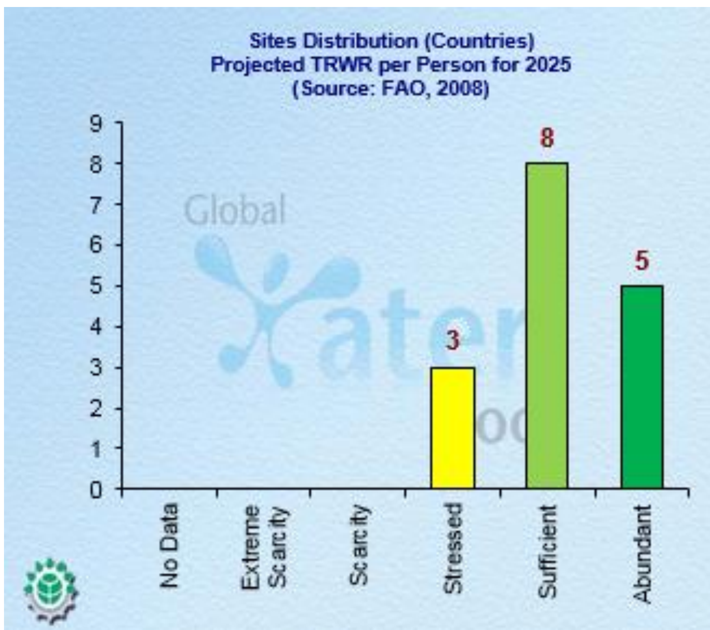


Figure 43 FAO Projection for 2025 of Total Renewable Water by Country Average of HAC Facilities

The GWT has a veritable bounty of country level information, but for the purposes of the impact of water on a company, the renewable water supply is very pertinent (CDP, 2013). The renewable water supply metric is recognized as a very good way to understand a locations water stress generally (Falkenmark et al., 1989). If there is ample renewable water, the facility will get the water it needs and the cost generally will not be high. However, if a facility is in an area of low renewable water supply, the opposite is likely the case.

To demonstrate the difference, the GWT has maps of both data sets for renewable water supply; Figure 44 and Figure 45 demonstrate the difference. Although, as mentioned previously, the data for the FAO renewable water metric and the WRI renewable water metrics are not exactly the same, the datasets do demonstrate the difference between country level data and watershed level data. However, the Falkenmark values for renewable water still apply with the 1700 m^3/person per year being the minimum to not be in a stressed state (Falkenmark et al., 1989).

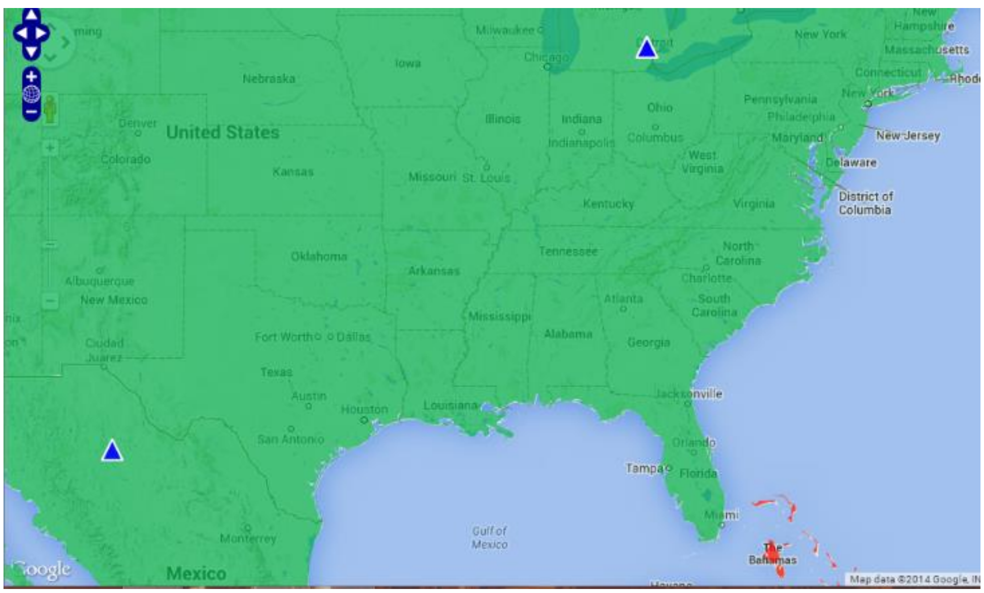


Figure 44 GWT Renewable Water per Person FAO 2008 Country Level Data

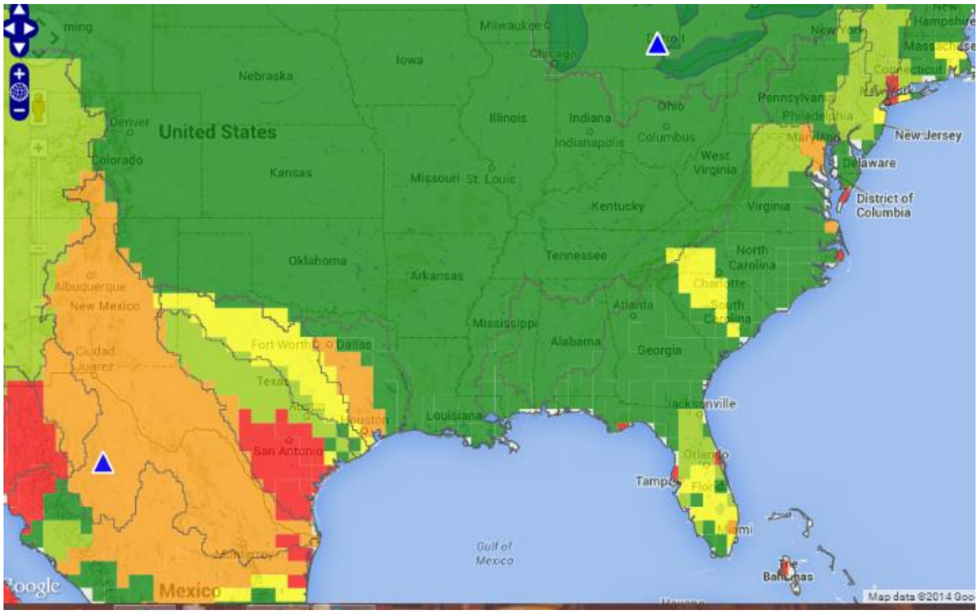


Figure 45 GWT Annual Renewable Water per Person 1995 WRI Watershed Level Data

For example, in Figure 44, the United States, Canada, and Mexico are shown as having abundant water, with the Bahamas having extreme scarcity. In Figure 45 different regions in a given country have vastly different levels. Intuitively, this concept makes sense. If a country has abundant water in most places, it will be shown as having abundant water even if there are regions in the country where the water situation is stressed. The watershed level data is local, and is based on the water situation that a given watershed is exposed to (Joost Schornagela, 2012). When a company or group is trying to assess the water situation at a facility, the watershed level data is more likely to give a more accurate picture of the water situation than a country level data because the local water situation is what affects the facilities water supply (Joost Schornagela, 2012). Similar to the country level databases and their water metrics, there are other metrics in the GWT besides the particular ones covered.

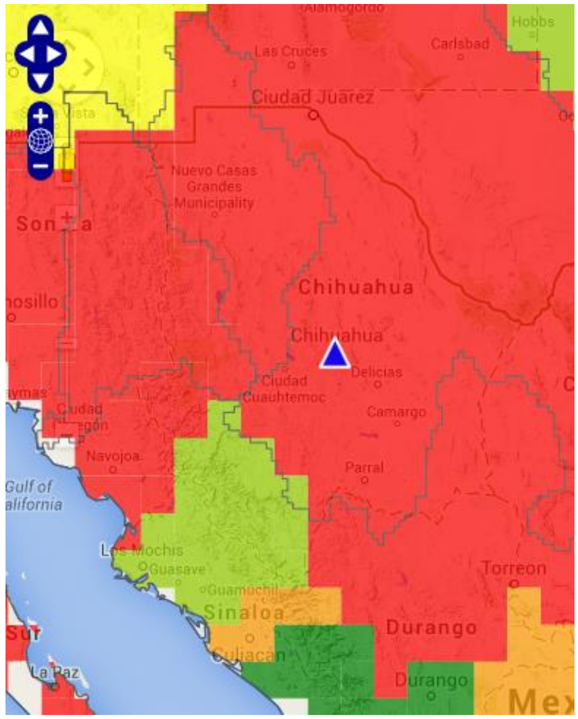


Figure 46 Watershed Level Projected Annual Renewable Supply per Person 2025

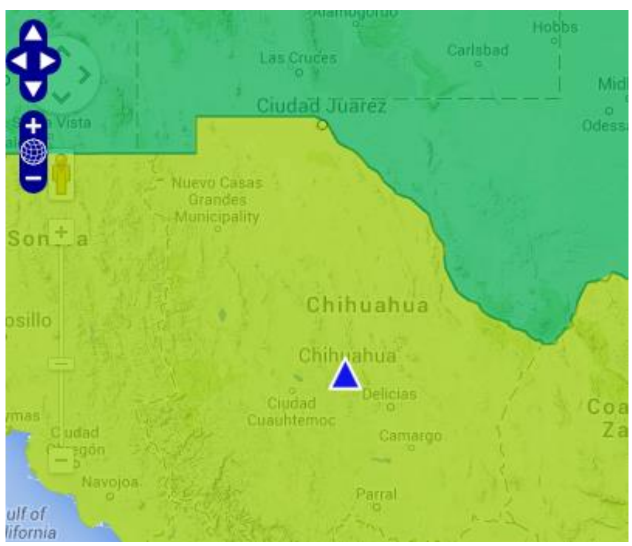


Figure 47 Country Level Projected Total Renewable per Person 2025

For example, the HAC's facility in Mexico has a vastly different stress rating from the watershed level metrics than the country level. It is located at 28.64° North, 106.1° West. For all of the country-level metrics, the average of a given metric in all of Mexico is shown, as in Figure 47. For the watershed, data based metrics, such as Watershed Level Projected Annual Renewable

Supply per Person in the stress level is local and detailed. However, there are differences in the way these metrics are calculated and their datasets. Because of that, it is difficult to compare the different types of metrics directly. In lieu of a direct comparison, it is clear that the metrics disagree with each other to such a degree (Abundant vs Scarcity) that they cannot both be correct. For example, Figure 46 and Figure 47 show roughly the same projection, a renewable water supply per person for 2025, and yet the metrics plotted on the map are completely different. As this example contains two projections, it is entirely possible that they are both wrong. However, they cannot both be right.

5.8 Overall Results of the Global Water Tool

The GWT has a variety of output results. The results break down into two categories. First, the direct data results that are categorized, into one of five stress states according to the Falkenmark index or state definitions for a particular metric.. For example, the Mean Annual Relative Water Stress Index values are a ratio that does not follow the Falkenmark index, but the results are still broken down into a variety of stress states, as shown in Figure 34, Figure 36, Figure 36 and Table 16. The best aspect of the GWT is the variety of information that the user can generate from the needed inputs.

The ability to map the data, have an overall view of facilities, and see the raw data is very useful. It allows the user to trace back exactly why the tool is giving out the information that it is, and the user can have a very thorough understanding of what the results are communicating. The HAC's Mean Annual Relative Stress Index (MAR) metric will be used as an example of all the ways the tool outputs the information and how that can be useful. Figure 34, Figure 36, and Table 17 show the ways the MAR metric can be output. The dashboard view (Figure 34) is useful to get a quick overview of how the entire company looks according to this metric. From Figure 34 it is immediately clear that one facility is shown as being in a severe state, and the rest of the facilities are in a low stress state. Figure 36 shows all of the facilities with the MAR mapped. This capability helps the user understand the regions that are affected by this metric and shows which facility is shown in a severe state (For the HAC, it is Mexico Car). The GWT allows the user to see exactly where the data came from, what the values of the metric are, an overall view of the company, and a map of the facilities and metrics.

However, there are a few problems with the tool. There is conflicting information as discussed previously with the watershed level data and the country level data. The problem boils down to the fact that not every location in a country is necessarily experiencing the same water situation. That is not to suggest that the country level information is not useful, but it needs to be in context. Country level results do not necessarily show the local water situation, which is what typically affects operations (Schornagela, Nielec, Worrellb, & Böggemannd, 2012). However, it is sometimes the only information available for a given metric or location, and then it is the most useful information for analyzing the water situation.

5.8.1 Use of Results

Companies or organizations can use the results of the GWT's analysis. First, facilities that are found to be in stressed locations can be prioritized for water-saving investments such as water recycling. Second, the projections can be used for planning future expansions and help the decision makers to avoid potentially stressed water supplies.

To understand how the two main metrics from the tools work, it is important to understand how they are calculated. The stress indicators in the GWT follow the Falkenmark index, which is the available water per year divided by the total people living in either the watershed or country. The GWT scarcity definition is a ratio of the available water to the total water withdrawal.

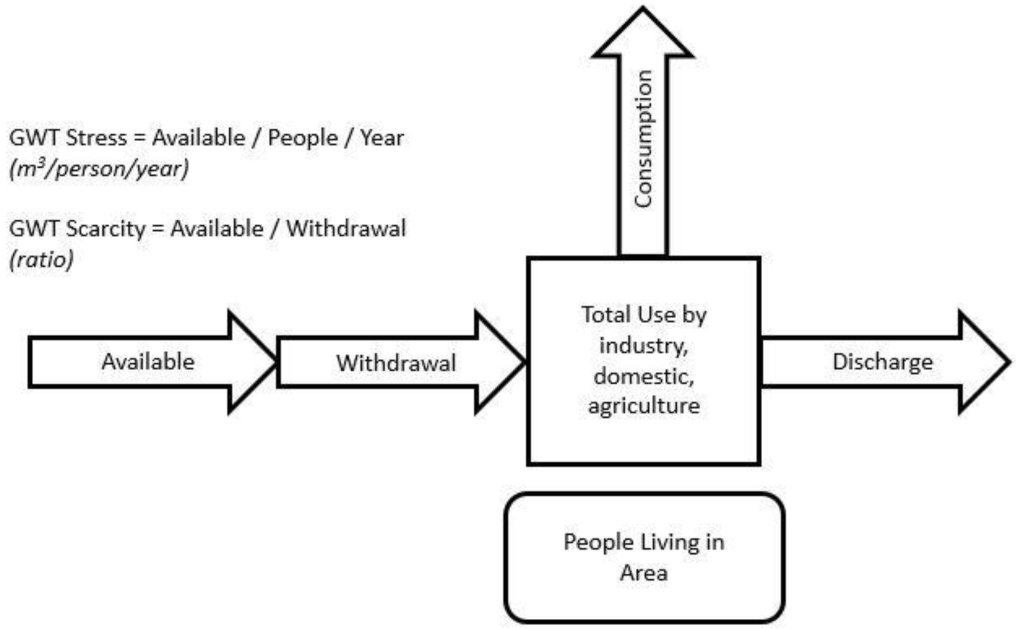
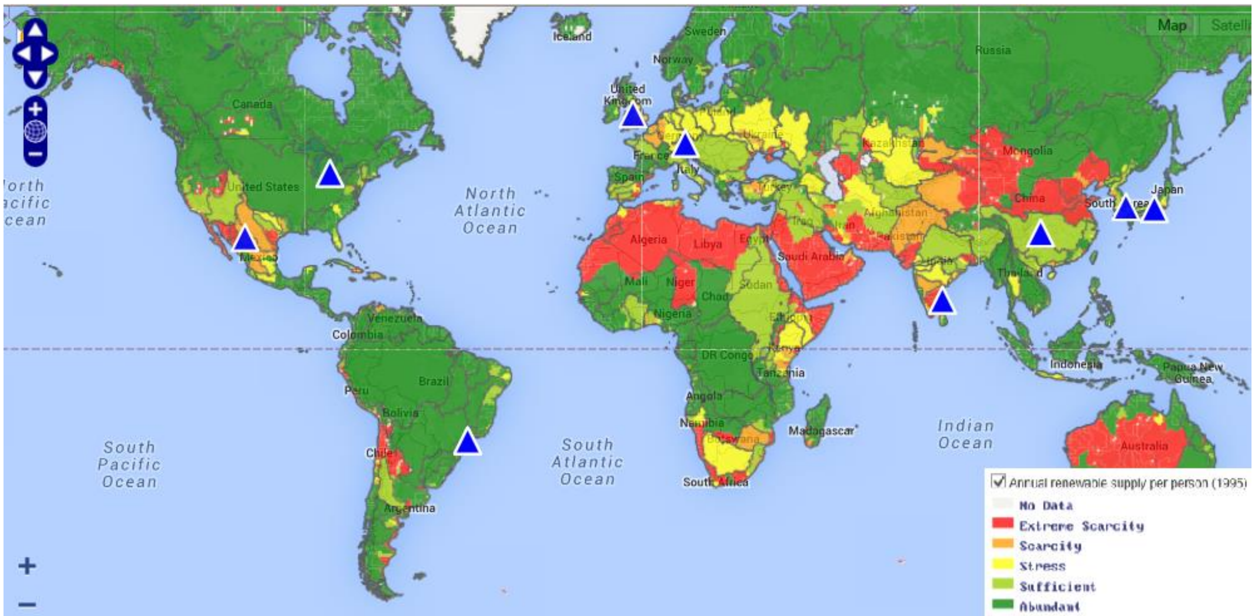


Figure 48 GWT Stress and Scarcity Definitions Graphic

5.9 Summary of Chapter 5

Once it is understood exactly what the tool results are and how the tool arrived at the output the results can be useful. Having an in depth understanding of the water profile and examining the results can help an organization understand their water risks and stresses. According to Schornagela, understanding the exact local water situation is critical (Joost Schornagela, 2012). The more localized results are more likely to give good guidance on the exact water situation at a location. Once the facilities risk metrics are understood, an organization can take steps to alleviate that risk by reducing use, shifting locations, or changing water strategy. For the HAC, the GWT found that the locations with the highest stress and risk were located in India, Mexico, and UK. Armed with this information, the HAC executives could now take steps to reduce that risk and potentially help the company.

Figure 49 GWT Annual Renewable Supply per Person 1995 with HAC Locations



CHAPTER 6 WATER RISK FILTER ANALYSIS OF HYPOTHETICAL AUTOMOTIVE COMPANY

6.1 Water Risk Filter Approach

The Water Risk Filter (WRF) is an online tool (http://waterriskfilter.panda.org), unlike the GWT, that stores locations and their information and has maps of water metrics and other analyses. The WRF is continuously updated by the World Wildlife Foundation, and the results for this thesis came from the period of July 2014 to February 2015. The updates to the WRF *may* mean that results from the current iteration of the tool do not match results from this thesis. Additionally, the questionnaire may be updated, but the same inputs will *most likely* still be applicable for the WRF.

The same inputs to the GWT were input, albeit in a different fashion. The web-based WRF keeps the facilities in a list and the user fills out a survey of a variety of water-related questions. From the WWF: "This tool helps companies and investors ask the right questions about water. It allows you to assess risks and offers guidance on what to do in response." (WWF, 2013)

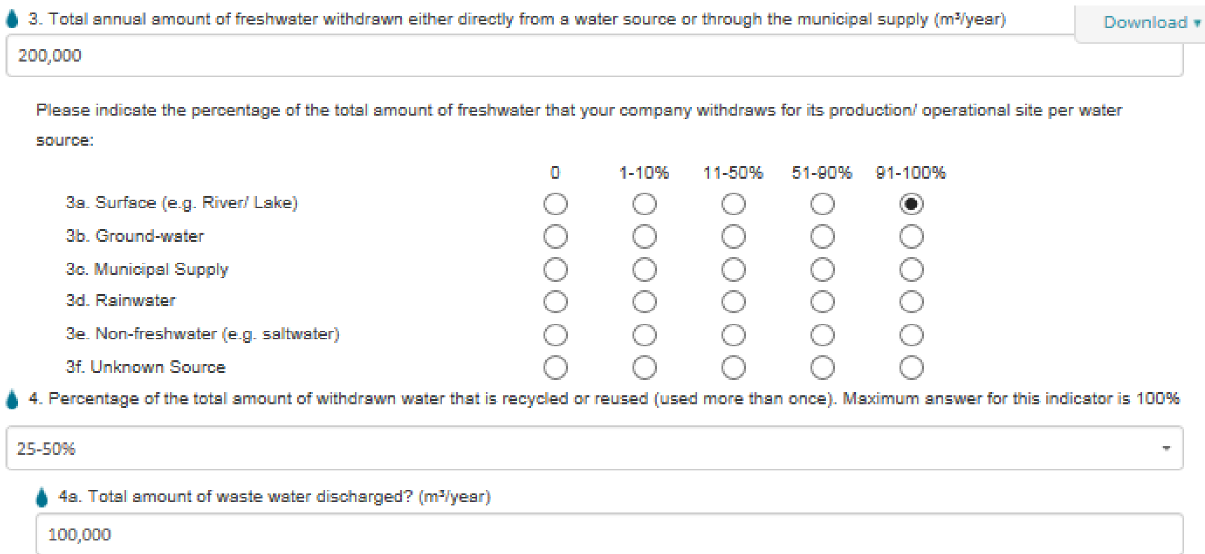
The WRF was designed to be used by non-water experts. The tools tries to give as much output as possible with whatever input is given. For example, questions can be left blank, and it will not cause any errors. In addition, the weighing scheme is simple (and can be adjusted) and has preset values for a given industry. The preset default weights are from WWF experts.

6.2 Water Risk Filter Questionnaire

The input into the WRF tool consists of 30 questions, which include questions for the inputs that match the HAC profile. The HAC profile was input into the survey, and all of the other questions were left blank. The inputs were limited to keep the tools operations as consistent as possible. Although the WRF includes questions about water quality and pollution, for the purposes of this thesis they were left blank. The complete questionnaire and Brazil Car response are located in Appendix A. The WRF questionnaire also includes questions that are not included in the risk scores. These questions were included to encourage an organization to think about the particular topic (WWF, 2015b). The questions are divided into 6 categories, Physical Risk, Pollution, Physical Risk of Suppliers, Regulatory Risk, Reputational Risk, and optional questions for WWF for benchmarking or comments.

6.2.1 Physical Risk

The Physical Risk section of the questionnaire (partly shown in Figure 50) relates to the availability of freshwater for the facilities operation as well as the withdrawal, recycled water, and discharge from the facility. This section receives the inputs that were used in the GWT. For example, the Brazil Car facility withdraws 200,000 m^3 of water sourced from the surface. The amount of water recycled was 50,000 m^3, so the amount recycled was 25%, so the option selected in the WRF was 25-50%. Finally, the discharge was 100,000 m^3. The WRF gives the option for the receiving body of the discharge, but since the GWT does not have that input, it is left blank.



3. Total annual amount of freshwater withdrawn either directly from a water source or through the municipal supply (m³/year) Download ▾

200,000

Please indicate the percentage of the total amount of freshwater that your company withdraws for its production/ operational site per water source:

	0	1-10%	11-50%	51-90%	91-100%
3a. Surface (e.g. River/ Lake)	○	○	○	○	●
3b. Ground-water	○	○	○	○	○
3c. Municipal Supply	○	○	○	○	○
3d. Rainwater	○	○	○	○	○
3e. Non-freshwater (e.g. saltwater)	○	○	○	○	○
3f. Unknown Source	○	○	○	○	○

4. Percentage of the total amount of withdrawn water that is recycled or reused (used more than once). Maximum answer for this indicator is 100%

25-50%

4a. Total amount of waste water discharged? (m³/year)

100,000

Figure 50 WRF Physical Questionnaire Section

6.2.2 Pollution

The HAC Profile does not include any water pollution information, and the information is difficult to ascertain without testing, and is out of the scope of this thesis. The WRF has default responses for different industries. The list of industries is substantial (much longer than the Aqueduct list), but for the purposes of this thesis the selection will be: Manufacturing of: industrial goods, household goods, home construction, personal leisure goods, (and – suppliers). This will be referred to as manufacturing profile for simplicity. The default pollution inputs for manufacturing are shown in Figure 51. For an example of another industry, Figure 52 shows the default response for the agricultural industry (animal products specifically).

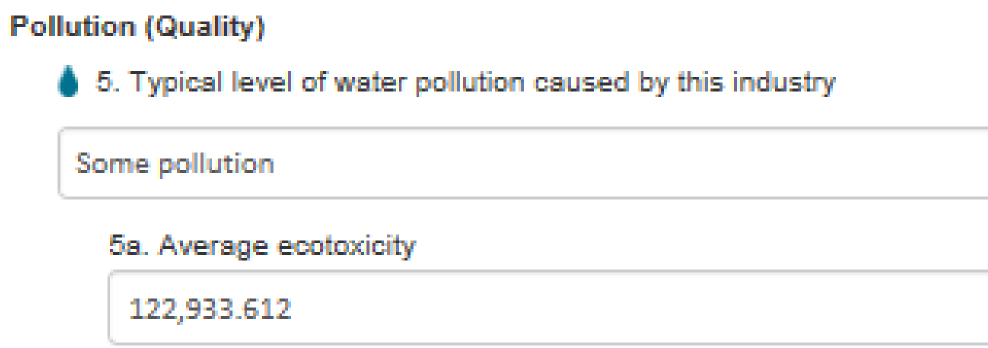


Figure 51 WRF Manufacturing Pollution Default Responses

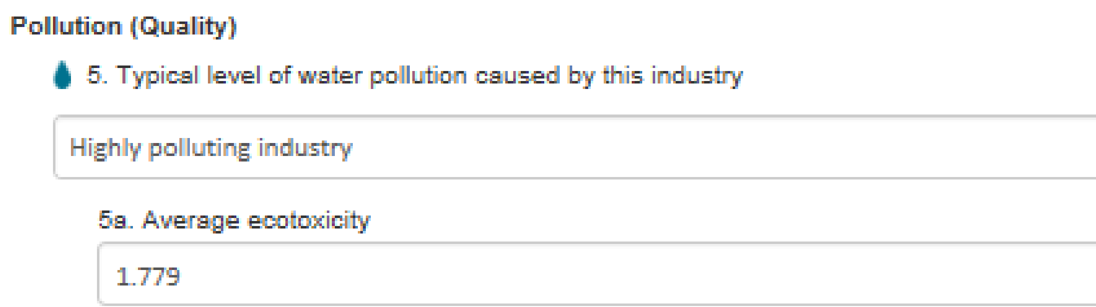
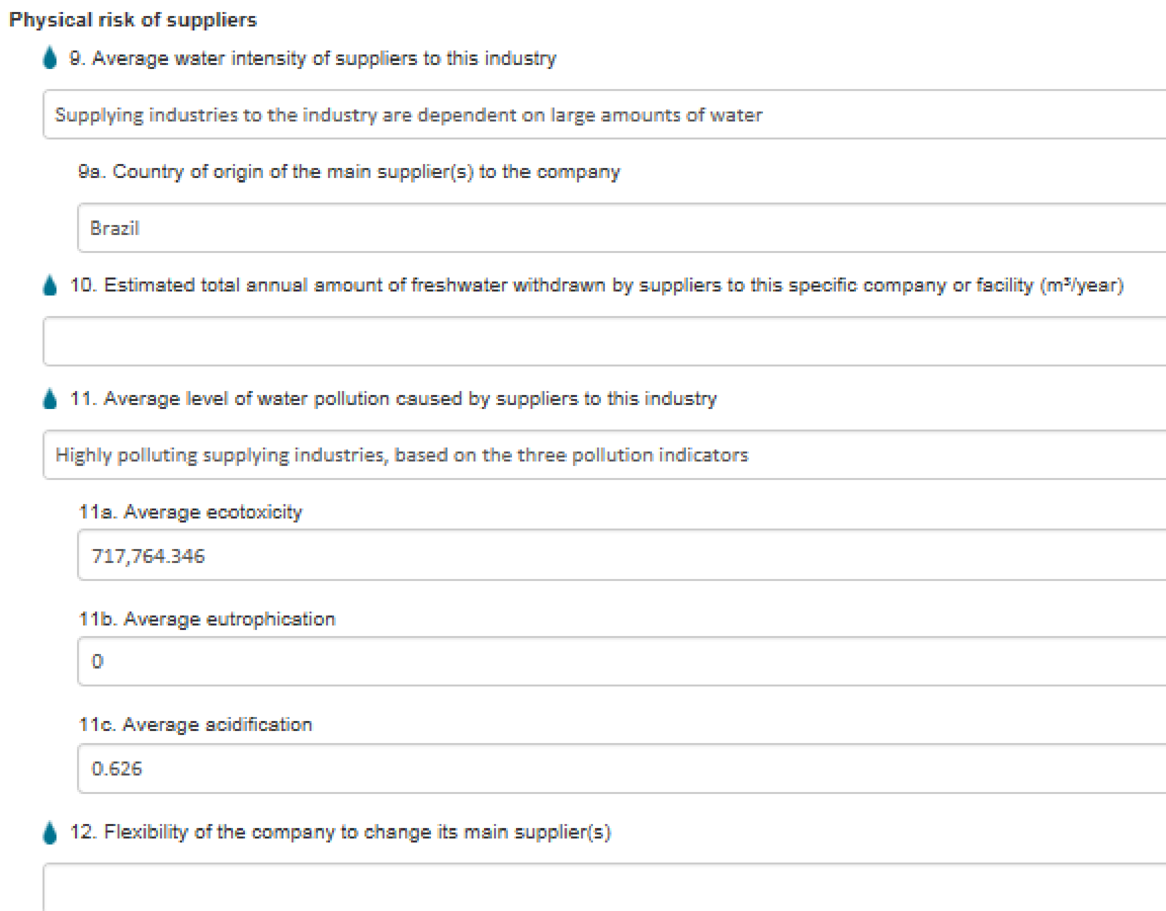


Figure 52 WRF Agricultural Industry Pollution Default Responses

6.2.3 Physical Risk of Supplier

The HAC has no supplier information, so the only inputs into the questionnaire are the defaults for the manufacturing industry. Other industries have different responses, but for the purposes of this thesis, they will not be used. However, the defaults for manufacturing will be left in the questionnaire. The manufacturing defaults are shown in Figure 53.


Physical risk of suppliers

9. Average water intensity of suppliers to this industry

Supplying industries to the industry are dependent on large amounts of water

9a. Country of origin of the main supplier(s) to the company

Brazil

10. Estimated total annual amount of freshwater withdrawn by suppliers to this specific company or facility (m^3/year)

11. Average level of water pollution caused by suppliers to this industry

Highly polluting supplying industries, based on the three pollution indicators

11a. Average ecotoxicity

717,764.346

11b. Average eutrophication

0

11c. Average acidification

0.626

12. Flexibility of the company to change its main supplier(s)

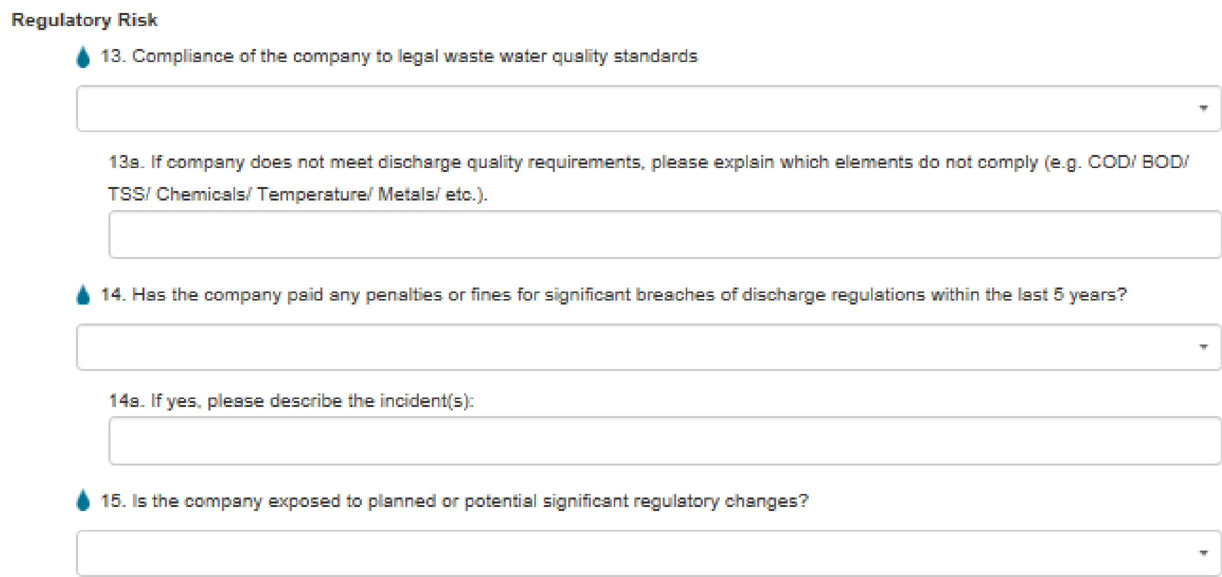
Figure 53 WRF Manufacturing Defaults for Suppliers

6.2.4 Regulatory Risk

The Regulatory Risk section of the questionnaire is three questions related to compliance, penalties (such as fines), and if the company has potential significant regulatory issues. All of the questions can be left blank, so they will be to make the WRF inputs match as closely as possible with the other tools inputs.

6.2.5 Reputational Risk

The reputational risk section of the questionnaire relates to a company's media exposure, stakeholders that may be impacted, and engagement with other stakeholders. This section was left blank to keep the inputs limited.


Regulatory Risk

13. Compliance of the company to legal waste water quality standards

13a. If company does not meet discharge quality requirements, please explain which elements do not comply (e.g. COD/ BOD/ TSS/ Chemicals/ Temperature/ Metals/ etc.).

14. Has the company paid any penalties or fines for significant breaches of discharge regulations within the last 5 years?

14a. If yes, please describe the incident(s):

15. Is the company exposed to planned or potential significant regulatory changes?

Figure 54 WRF Regulatory Risk Questions

6.2.6 Optional Benchmarking Questions

The optional questions are the production information, and are left blank because these inputs do not count toward the risk score and since the HAC does not exist, it would be disingenuous to have WWF include the information.

6.3 Water Risk Filter Results for the HAC

First, it should be noted that these results from the WRF are from the period of July 2014 to February 2015. The WRF *may* be updated as time progresses so results from a current iteration of the tool *may* be different the results shown in this thesis.

The WRF results are grouped into three categories. First, individual results for each facility. This includes a heat map of risks (Figure 56) and allows weights to be put on different metrics (such as scarcity risk, Figure 58). Second, a plot of all the facilities and their risks on a plot of basin and company related risks (Figure 55). Finally, WRF can output reports of the results. The reports are company level, facility level, and a CDP report to aid with responding to the CDP Questionnaire. The reports also link to the mapping feature of WRF that is similar to the mapping feature in the GWT. Additionally, the reports link to the Mitigation section of the WWF website (WWF, 2013).

6.3.1 Facility Assessment and Weights

The individual facility results will be demonstrated with the Brazil Car facility. All of the facilities results are shown in Figure 55, but the Excel file that WRF outputs does not quite show all of the results and abilities of the tool. The first result that appears is the heat map of "Company related risk results" and Basin related risk results" (WWF, 2015d). The Brazil Car heat map is shown in Figure 56, with the various facilities plotted as dots on a plot of company risk and basin risk axes, and the types of risks are clearly split in the heat map. The company related risks encompass are calculated primarily through the responses in the questionnaire, and the basin related risks are based completely on the GPS position of the facility (WWF, 2015d).

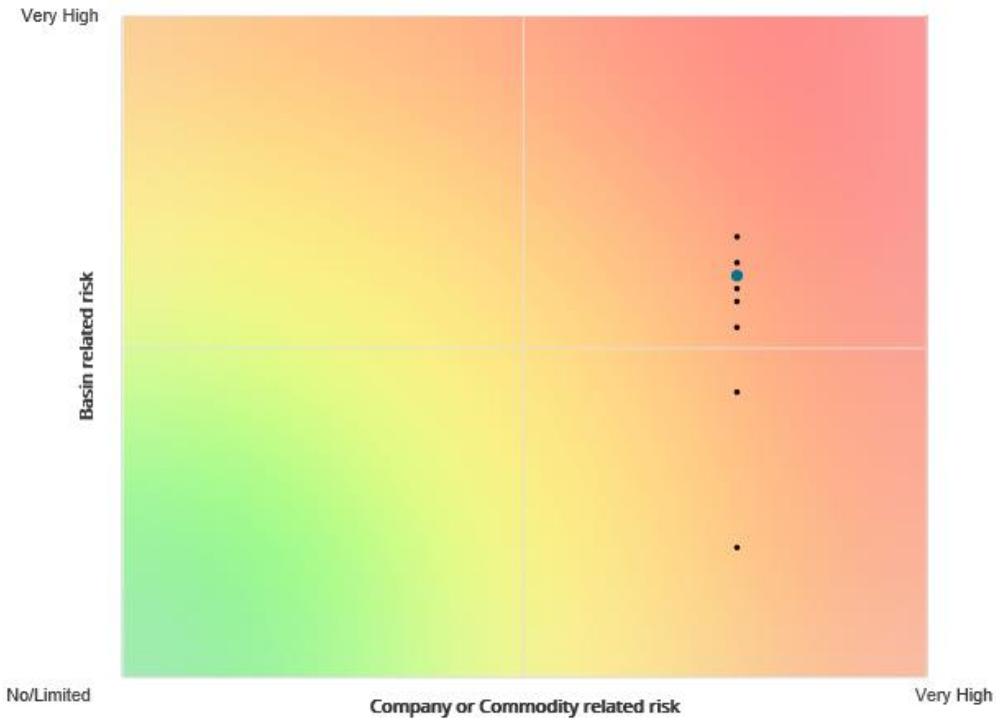


Figure 55 HAC Facilities Basin and Company Risk Heat Map, the dots on the heat map represent facilities, Brazil Car is represented by larger blue dot

The WRF allows the user to determine exactly why a particular score was assigned by examining the assessment itself. For example, the Pollution (quality) score in the Physical risk section is shown in the assessment Figure 57. The WRF gave the Brazil Car facility a “3 Some Risk” score (which means that WRF recommends mitigation and the stress state would be significant enough to cause interruptions (WWF, 2015a)), and included it into the overall “Total Company and Basin risk” score. The weight each category gets in each Total risk score can be adjusted. An overview of how the different scores compile into the total is shown in Figure 60. For the purposes of this thesis, the weights will remain at the default setting for manufacturing unless noted. The default manufacturing weight’s influence can be seen by examining the results of the WRF analysis and are shown in Figure 60 and Figure 59.

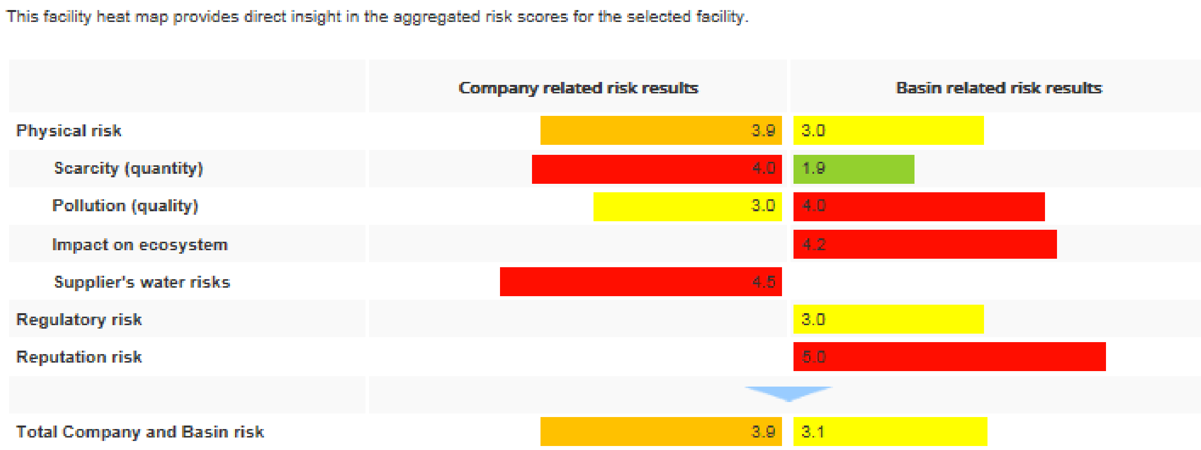


Figure 56 WRF Brazil Car Risk Heat Map

In Figure 57 the WRF is showing which Questionnaire questions influenced the pollution score as well as the assigned risk level for the specific metric. For Brazil Car, Figure 57 the pollution risk score is shown in addition to the survey answers. For Brazil Car, only the default response to question 3 ("Total amount of freshwater withdrawn…") caused any risk at all. The other questions are blank. Unlike the pollution score, the Physical risk Scarcity was an input from the HAC profile, and it is scored a High Risk score by the WRF. This is shown in Figure 58.

The main ideas of the WRF Facility Risks (Company and Basin) are summarized in a few key points:

- The Basin Risk score is completely dependent on the location of the facility
- The Company Risk score is primarily calculated from the questionnaire
- The weights of all of the different metrics can be adjusted
- WRF includes default weighing schemes for different industries

Physical Risk Pollution (Quality)	5	3 Some risk	Typical level of water pollution caused by this industry
	5a		Average ecotoxicity
	5b		Average eutrophication
	5c		Average acidification
	6	No data available	Requirement of treatment/ purification of the water the company withdraws before use in operations
	7	No data available	Percentage of the withdrawn freshwater that is discharged with some level of pollution
	8	No data available	Quality measurements of the water the company withdraws and discharges by the company itself or an external company
	8a		If no, please explain:

Figure 57 Physical Risk Pollution section of WRF for Brazil Car

Physical Risk Scarcity (Quantity)	1	No data available	Importance of having sufficient amounts of clean freshwater available for the production/ operational site's operations	
	2	No data available	Problems the company has/had withdrawing/obtaining the required amount of water for its operations	
	2a		If yes, please explain:	
	3	4 High risk	Total annual amount of freshwater withdrawn either directly from a water source or through the municipal supply (m^3/year)	200000

Figure 58 Physical Risk Scarcity score from WRF for Brazil Car

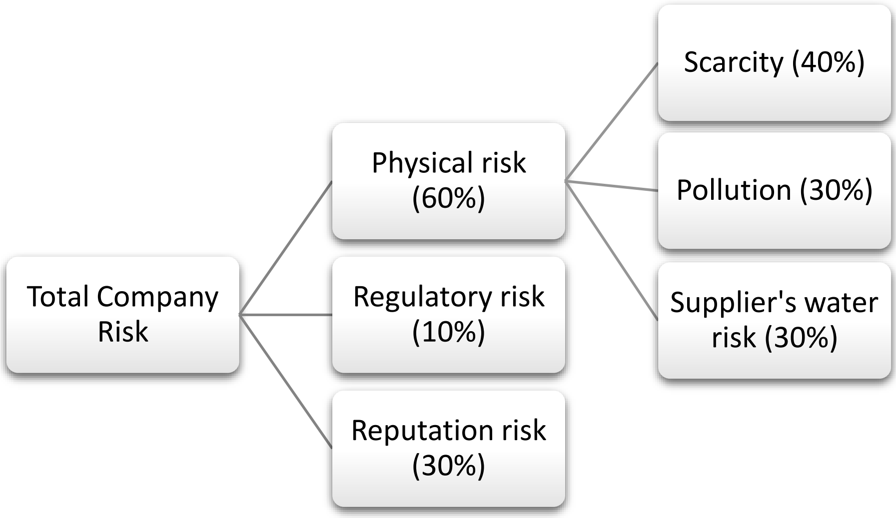


Figure 59 WRF Company Risk Weight Hierarchy, Manufacturing Profile Weight Percentages are shown

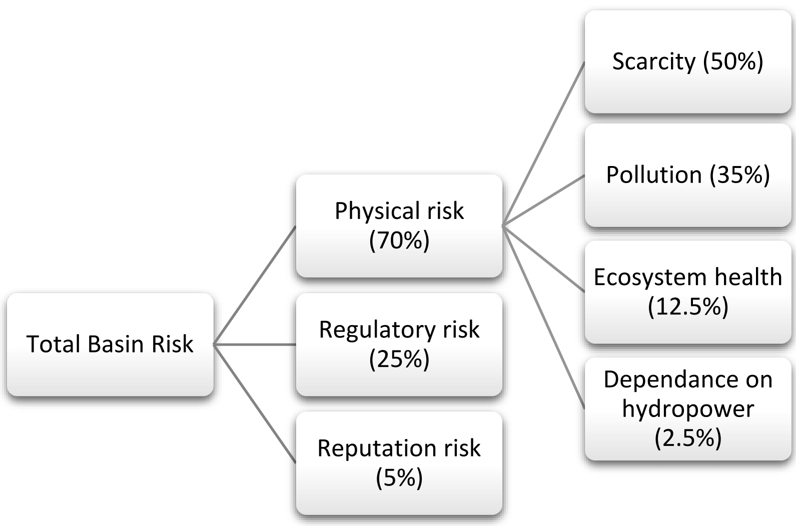


Figure 60 WRF Basin Risk Weight Hierarchy, Manufacturing Profile Weight Percentages are shown

6.3.2 Brazil Car Total Risk

The risk heat map for Brazil Car (Figure 56) condenses a great deal of information. The Physical Risk is the only calculated section of the three main sections because all of the responses for those sections were left blank. Additionally, the "Impact on ecosystem" is blank because it is only taken into account in the Total Basin Risk. The blank results are shown in Figure 61. Because of the blank sections, the Total Company risk for the purposes of this thesis is really just the Physical Risk score because of the nature of the input information.

Figure 61 Brazil Car WRF Heat Map with arrows indicating blank sections

The Total Company Risk is rated as High Risk. The main contributors to that score are the scarcity and the suppliers' water risk. The pollution risk score may have been the lowest but it was still rated at Some Risk. Those metrics are weighed as shown in Figure 59. Those weights can be adjusted by the user, but for consistency with Aqueduct, the default Manufacturing/Industrial weights will be left unless otherwise noted.

Figure 62 Brazil Car WRF Individual Heat Map with Company Risks Outlined

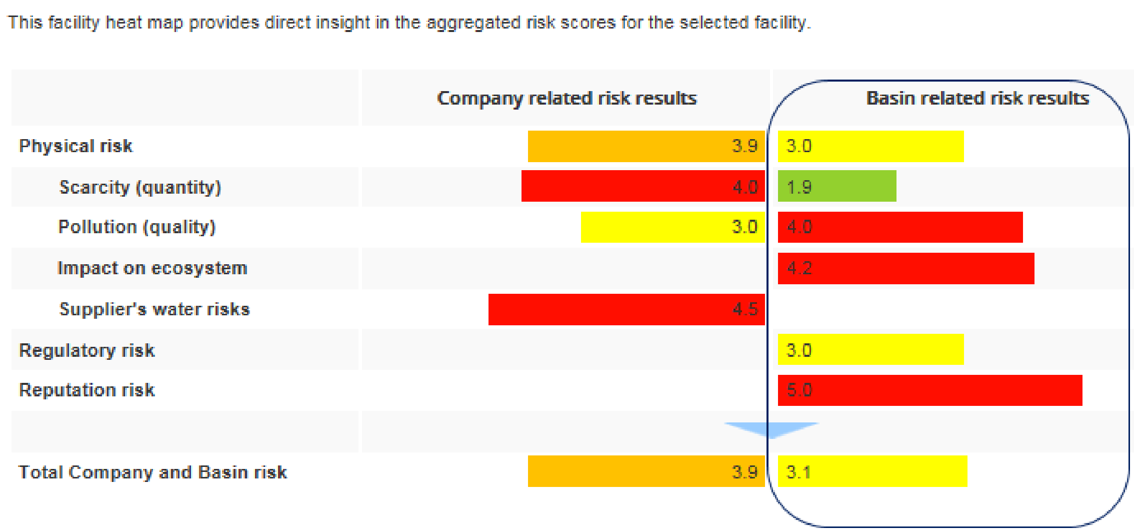


Figure 63 Brazil Car WRF Individual Heat Map with Basin Risks Outlined

The Total Basin Risk for Brazil Car is based entirely on the location of the facility. For Brazil Car, that total risk score is 3.1, which is Some Risk. This score is calculated based on the weights given in Figure 60 and the individual metric scores can be viewed in the Survey results. Figure 65 shows a selection of the metric from the Total Basin Risk and their values. All of the metric results are available, and are shown in total for all of the facilities in Table 21.

6.3.2.1 WRF Equations of Stress/Scarcity

The WRF calculates stress and scarcity metrics different than the other tools covered in this thesis. First, it should be noted that unlike the GWT, the WRF calculates both stress and scarcity in effectively the same manner. The Water Stress from GLOWASIS is calculated as a ratio of the water consumption to the availability of water in a given location (a grid-cell for GLOWASIS) (WWF, 2014a). Similarly, the Water Scarcity Metric from WFN is calculated as a ratio of the water consumption to the availability of water for a given watershed (WWF, 2014a). Negating the geographic difference, both stress and scarcity are calculated by Equation 4 for the WRF.

Equation 4 WRF Stress or Scarcity Calculation

$$Stress\ or\ Scarcity = \frac{Total\ Water\ Consumed}{Total\ Water\ Available}\ [\%]$$

The main issue with this calculation is that by most other sources and reports, water stress and/or scarcity are calculated using withdrawal as the nominator (Berrittella et al., 2007; Falkenmark et al., 1989; Herbst, 2009; ISciences, 2011; Joost Schornagela, 2012; Paul Reig, 2013; Rijsberman, 2006; UNDESA, 2013; WBCSD, 2011b). The Total Water Consumed, by definition (WWF, 2014a), is always less than the water withdrawal. Additionally, the Total Water Withdrawal is a better indicator of how *available* water is in a given location or watershed which is the point of a water stress or scarcity metric (Falkenmark et al., 1989).

6.3.2.2 WRF Metrics and Results Discussion for Brazil Car

The Brazil Car facility has a very high flood occurrence score as well as the drought occurrence. These are the two main contributors to the facility's Physical Risk score, because for the Scarcity metric it scores low risk (Figure 64). For the Total Basin Risk, all of the metrics are taken into account because they are all based on the location, and not on survey results.

The WRF metrics databases are unique for most metrics. The main databases that the WRF references for physical risks (which are typically the bulk of the Total Basin Risk) are the GLOWASIS water scarcity database ("GLOWASIS," 2015) and the Water Footprint Network ("Water Footprint," ; WFN, 2015). Additionally, most of the metrics used by the WRF are watershed-level or at the resolution of the data. Some notable exceptions are the Climate and Sanitation, but those do relate to a countries infrastructure and economy.

Most of the metrics in the WRF are intuitive (Agricultural Land) or similar to other water metrics discussed (Scarcity). However, the Climate metric is unlike any other metric covered so far in this thesis. According to the WRF the Climate Change metric: “Global distribution of vulnerability to climate change – impacts with enhanced adaptive capacity expanded scenario A2 using year 2050 with climate sensitivity equal to 5.5 degree C annual mean temperature. “ (WWF, 2014a) Essentially this metric is a measure of how well a country will be able to handle the predicted change in the climate according to the A2 scenario from the IPCC (IPCC, 2013).

The individual risk heat map from WRF for the Brazil Car location is a combination of the Total Company Risk and Total Basin Risk, with the company risk being based on the survey and location with the basin risk based exclusively on the location. The Total Company Risk is 3.9, which is very high and the Total Basin Risk is “Some Risk”. Each facility has the individual heat map that can be inspected in the same way that Brazil Car has.

1	1 Very limited risk	Annual average monthly blue water scarcity in this river basin (WFN) Basin level indicator	Abundant: 0 - 25%
1a	2 Limited risk	Annual average monthly blue water scarcity around the facility/commodity (GLOWASIS) Grid level indicator	Sufficient: 25 - 100%
2	1 Very limited risk	Number of months per year water scarcity exceding 100% in this river basin (Water Footprint Network) Basin level indicator	0 months

Figure 64 selection of WRF Basin Risk Scarcity Metrics

4	No data available	Groundwater overabstraction	
5	2 Limited risk	Forecasted impact of climate change Country level indicator	Vulnerability Index: 2 of 4: Limited impact
6	5 Very high risk	Estimated occurrence of droughts (2010-2013) Grid level indicator	>25% of the country affected by a severe drought in every year during the last 3 years
6a	5 Very high risk	Estimated occurrence of droughts (2011-2013) Grid level indicator	>25% of the country affected by a severe drought in every year during the last 2 years
6b	5 Very high risk	Estimated occurrence of droughts (2012-2013) Grid level indicator	>25% of the country affected by a severe drought in every year during the last 12 months
7	5 Very high risk	Estimated occurrence of floods Basin level indicator	Very high: >10 floods reported between 1985 and 2013

Figure 65 selection of physical WRF Basin Risk Metrics for Brazil Car

6.3.3 Water Risk Filter All Facilities Results

The WRF has two ways to output the total risk profile for the HAC. The first is a map of all the facilities plotted based on their Total Company and Total Basin Risks shown in Figure 66. This chart is useful to get a quick idea of the general risk exposure of the entire HAC. From this chart, it can be seen that the facilities have a variety of Total Basin Risks, but their scores are all at least "Some Risk." Additionally, all of the facilities appear to have the same Total Company Risk. This is particularly interesting because the facilities have a variety of water usage inputs into the survey. All of the facilities withdrawal is between 110,000 m^3 and 2,000,000 m^3 with similar ratios for recycling and consumption. This must mean that none of the facilities had different enough survey results to justify a different score according to the WRF. This is particularly applicable for the Car and Truck variants of facilities. For each pair (USA, India, and China) the company risk was the same despite the difference in water withdrawal at the exact same location.

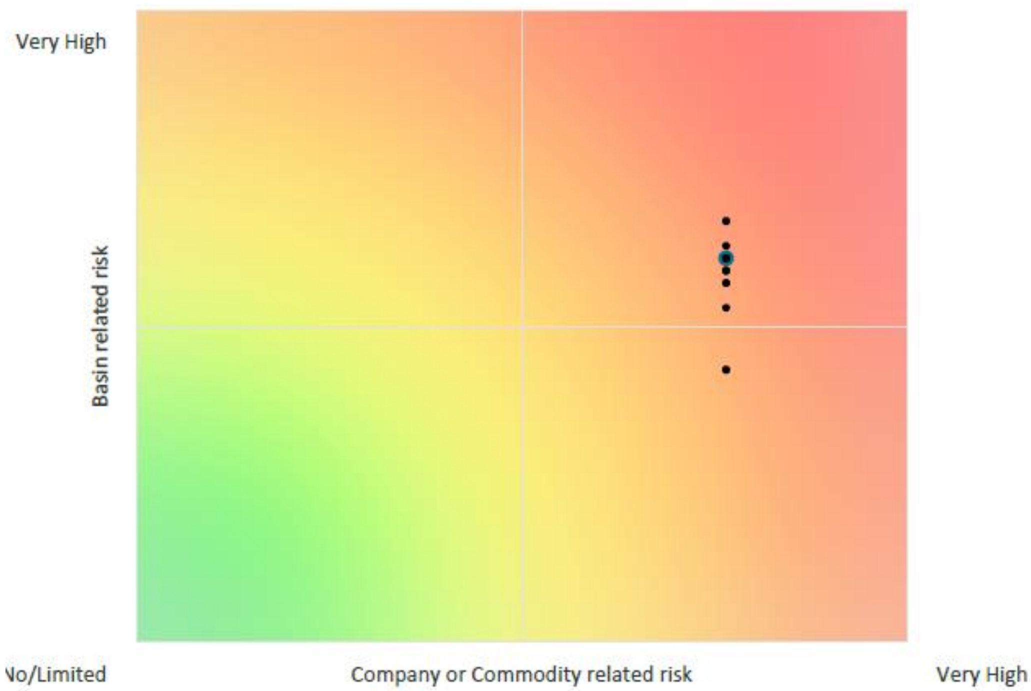


Figure 66 WRF All HAC Facilities Plotted with Brazil Car Highlight

Table 20 shows this pattern. All of the facilities are scored the same despite the differences in the water use information for the Car and Truck locations. The default values were used for the pollution and suppliers section based on the manufacturing profile, but all of the water use information was unique to a facility generally.

Table 20 WRF Total Company Risks for the HAC Facilities

Name of facility	Final score Company related risk	Physical risk	Physical - Scarcity/ quantity	Physical - Pollution/ quality	Physical - supply chain risk
USA Car	3.9	3.9	4	3	4.5
USA Truck	3.9	3.9	4	3	4.5
India Car	3.9	3.9	4	3	4.5
India Truck	3.9	3.9	4	3	4.5
Germany Car	3.9	3.9	4	3	4.5
Mexico Car	3.9	3.9	4	3	4.5
China Car	3.9	3.9	4	3	4.5
China Truck	3.9	3.9	4	3	4.5
Japan Car	3.9	3.9	4	3	4.5
Japan Truck	3.9	3.9	4	3	4.5
South Korea Car	3.9	3.9	4	3	4.5
Brazil Car	3.9	3.9	4	3	4.5
Brazil Truck	3.9	3.9	4	3	4.5
UK Super Luxury	3.9	3.9	4	3	4.5
Germany Engine	3.9	3.9	4	3	4.5
Brazil Transmission	3.9	3.9	4	3	4.5

6.3.3.1 Brazil Extreme Example

It is possible to fill out the WRF survey in such a way that the company risks are extremely high or extremely low. A facility called "Brazil Extreme" was created to demonstrate this. For the first example for the entire survey, the most high-risk option was chosen. For example, question 2 "Problems the company has/had withdrawing/obtaining the require amount of water for its operations" was answered "Yes, regularly". Additionally, the suppliers were listed in Afghanistan, which contributed to the extremely high supplier water risks. The company results from Brazil Extreme for the worst-case scenario are shown in Figure 67.

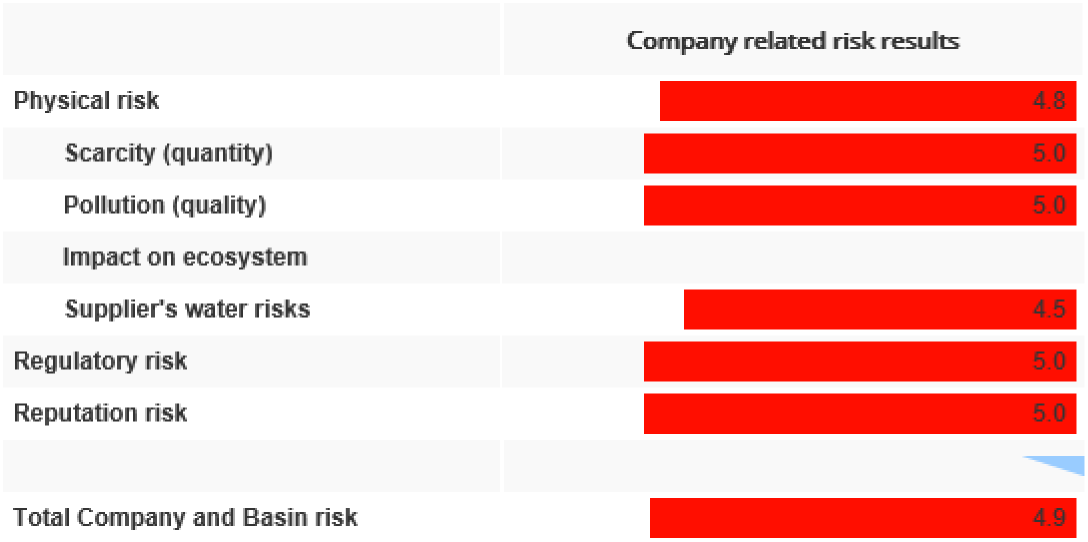


Figure 67 WRF Company Risk for Brazil Extreme location, showing a worst case scenario questionnaire response

Conversely, the questionnaire can be filled out in such a way that the company risk is extremely low. For example, for question 2 discussed previously, the answer ‘No’ was selected. The suppliers were listed as in Canada in order to lower the supplier risk.

Figure 68 WRF Company Risk for Brazil Extreme location, showing a best case scenario questionnaire response

6.3.4 WRF Total Basin Results

The Total Basin Risk for the HAC facilities is a completely different situation than the Total Company Risk. Each different location (reminder: some facilities are in similar locations) had a different risk profile. None of the facilities had a higher Total Basin Risk than 3.4 with manufacturing default weights, which corresponds with a risk rating of "Some Risk" according to the WRF. The facilities in Germany, Japan, and South Korea have the lowest risk with scores in the 2.2-2.7 range. The rest of the facilities were listed from 2.7 to 3.4. The Total Basin Risk includes more metrics than are listed in Table 20, and the complete list is included in the appendix.

One interesting note about the WRF water metrics is that there are significant gaps in the information that were not present in the GWT. In Table 21 all of the blank cells in the table are gaps in the dataset. Also of note, all of the facilities have at least one risk metric that is categorized as at least "High Risk". Because of this, it would be advisable for any user of this tool to understand that even though the total risks may not be particularly high; there is always the potential for one type of water risk to pose a serious threat to operations of the facility. For example, the South Korea Car facility has one of the lower Total Basin Risk scores (2.7) but it has a "High Risk" rating for both Number of Months in Severe Scarcity and Scarcity in Most Scarce Month. Both of those risks have the potential to affect the facility, and cannot be ignored.

Table 21 WRF Total Basin Risks for the HAC Facilities

Name of facility	Final score Basin related risk	Physical risk	Physical - Scarcity/ quantity	Physical - Pollution/ quality	Physical - dependence hydropower	Annual monthly average scarcity (WFN)	*Annual monthly average scarcity (GLWOASIS)*	Number of months severe scarcity (WFN)	*Number of months severe scarcity (GLWOASIS)*	Scarcity in most scarce month (WFN)	*Scarcity in most scarce month (GLWOASIS)*	*Groundwater*	Impact climate change	Occurence of droughts (3 year)	*Occurence of droughts (2 year)*	*Occurence of droughts (1 year)*	Occurence of floods
USA Car	3	3.2	2.7	4	2	2	5	2	5	5	5		1	1	1	1	3
USA Truck	3	3.2	2.7	4	2	2	5	2	5	5	5		1	1	1	1	3
India Car	3.4	3.2	1.6	5	2	2	5		4		5	2	2	1	1	1	4
India Truck	3.4	3.2	1.6	5	2	2	5		4		5	2	2	1	1	1	4
Germany Car	2.2	2.6	1.4	4	1	1	2	1	2	2	3	1	2	1	1	1	3
Mexico Car	3.2	3	2.9	3	2	2	1		1		1		2	5	5	1	3
China Car	3.1	2.8	1.7	4	2	1	1	1	1	1	1		4	3	2	1	5
China Truck	3.1	2.8	1.7	4	2	1	1	1	1	1	1		4	3	2	1	5
Japan Car	2.9	3.1	2.2	4	2	2	1		1		2		1	1	1	1	5
Japan Truck	2.9	3.1	2.2	4	2	2	1		1		2		1	1	1	1	5
South Korea Car	2.7	2.2	1	4	1	1	2		4		4		3	1	1	1	3
Brazil Car	3.1	3	1.9	4	5	1	2	1	3	1	5		2	5	5	5	5
Brazil Truck	3.1	3	1.9	4	5	1	2	1	3	1	5		2	5	5	5	5
UK Super Luxury	3	3.3	2.9	4	1	2	2		2		3		2	2	1	1	5
Germany Engine	2.2	2.6	1.4	4	1	1	2	1	2	2	3	1	2	1	1	1	3
Brazil Transmission	3.1	3	1.9	4	5	1	2	1	3	1	5		2	5	5	5	5

6.3.5 Mapping and Reports

Similar to the GWT, the individual results and company profile information is very useful, but the mapping capabilities help give context for the different metrics. The WRF has mapping features similar to the GWT, but the WRF can plot almost every metric and some of the metrics have even more detailed maps that are not available in any other tool. For example, the WFN Water Scarcity Metric is available in both an Annual Average (Figure 69) and a monthly average (Figure 70). This is a useful feature because it allows the user to examine a worst-case scenario for the metric. The WRF does have a 'Reports' section that creates automatic reports for individual facilities, the company as a whole, and a report that is intended to help with submitting the CDP Water disclosure.

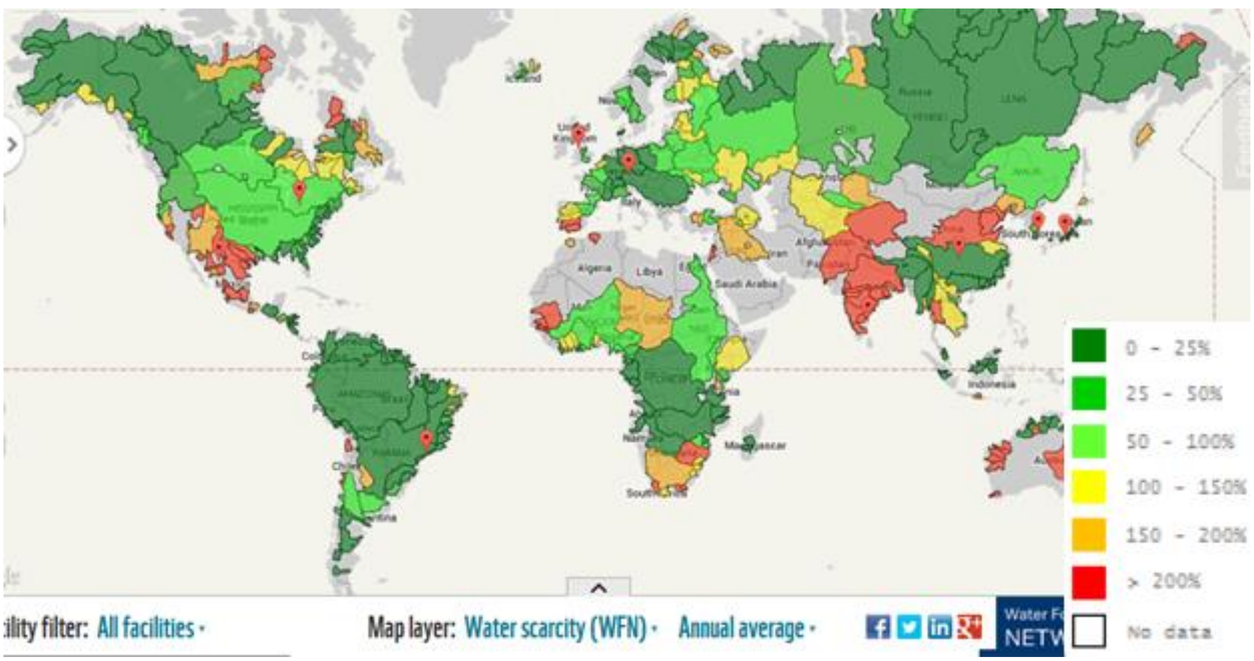


Figure 69 WRF Water Scarcity Annual Average

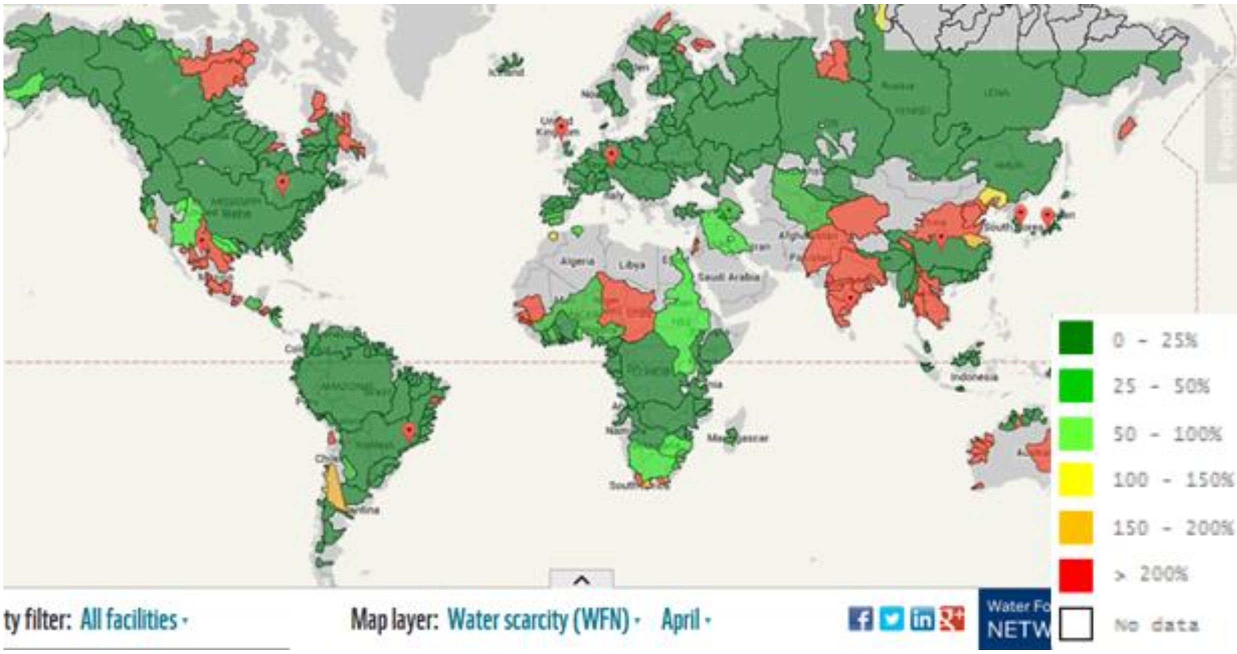


Figure 70 WRF Water Scarcity April Average

The 'Portfolio Report' is generated by the WRF automatically to give the user an overview of the main metrics that WRF emphasizes. The two metrics that are plotted are the Annual Average Blue Water Scarcity and Pollution. Also included in the report is the plot of each facility on a map of Total Basin Risk and Total Company Risk (Figure 66). The Annual Average Blue Water Scarcity and Pollution are shown in Figure 69 and Figure 71 respectively.

The WRF has some watershed and country level indicators, but it also has water metrics that have a resolution based on the available data and not any geographic or political constraints. For example, the Overall Pollution (Figure 71) and Water Stress (Figure 72) both are limited only by the resolution of the data.

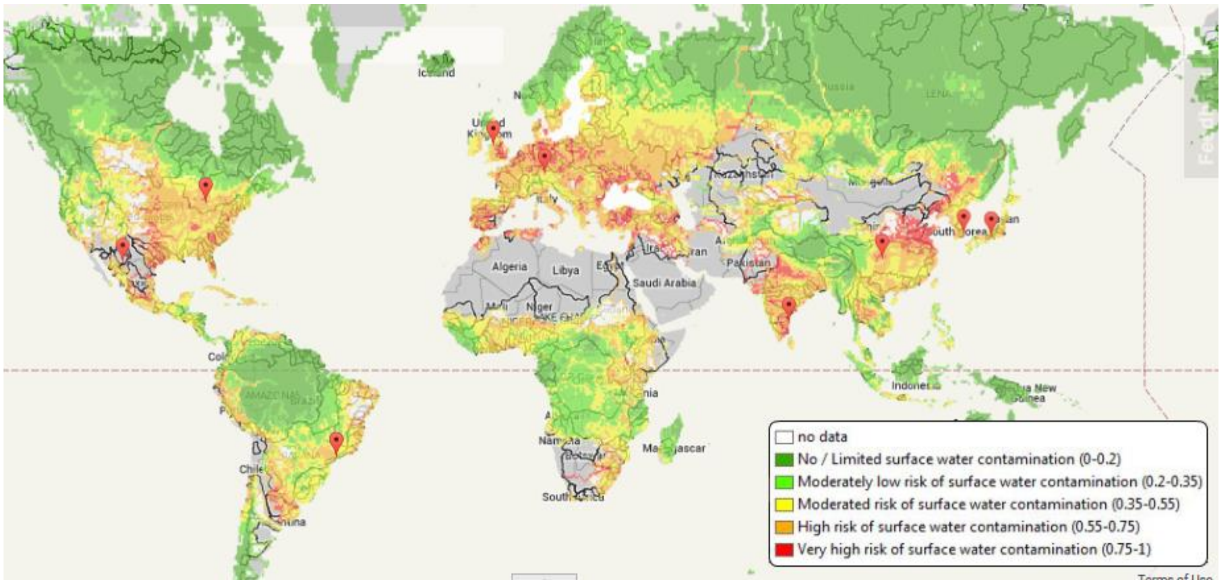


Figure 71 WRF Overall Pollution

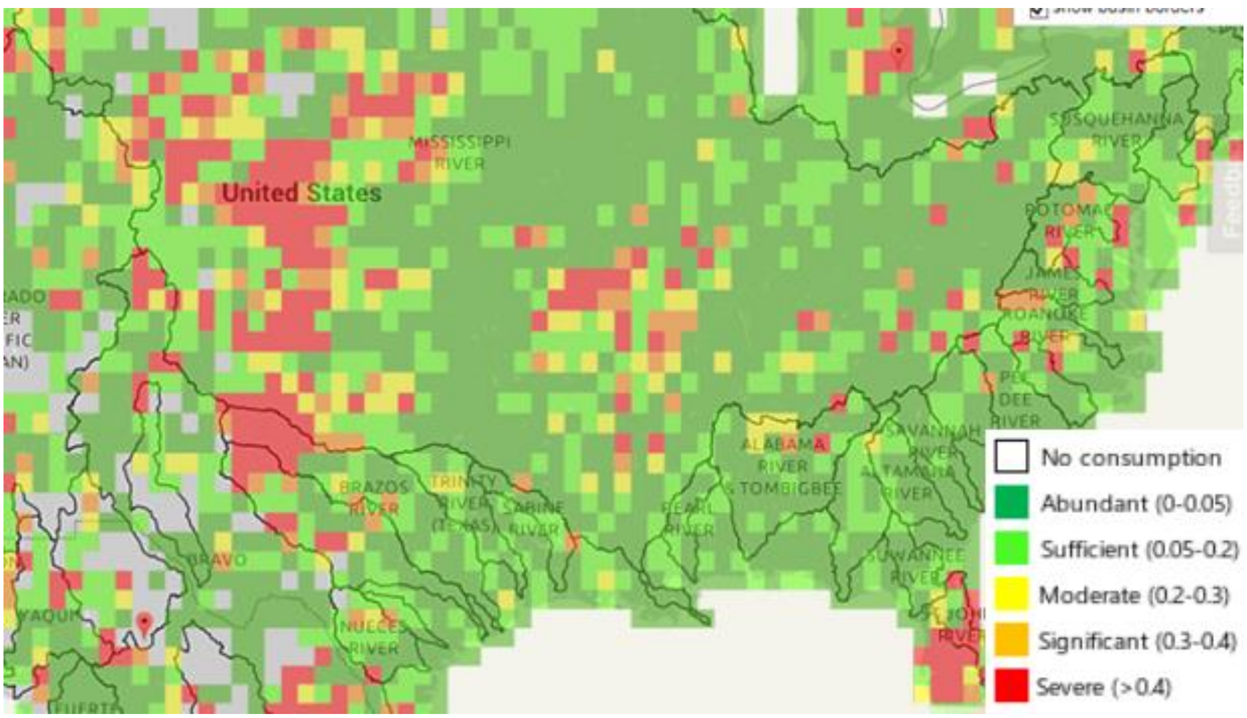


Figure 72 WRF Water Stress North America

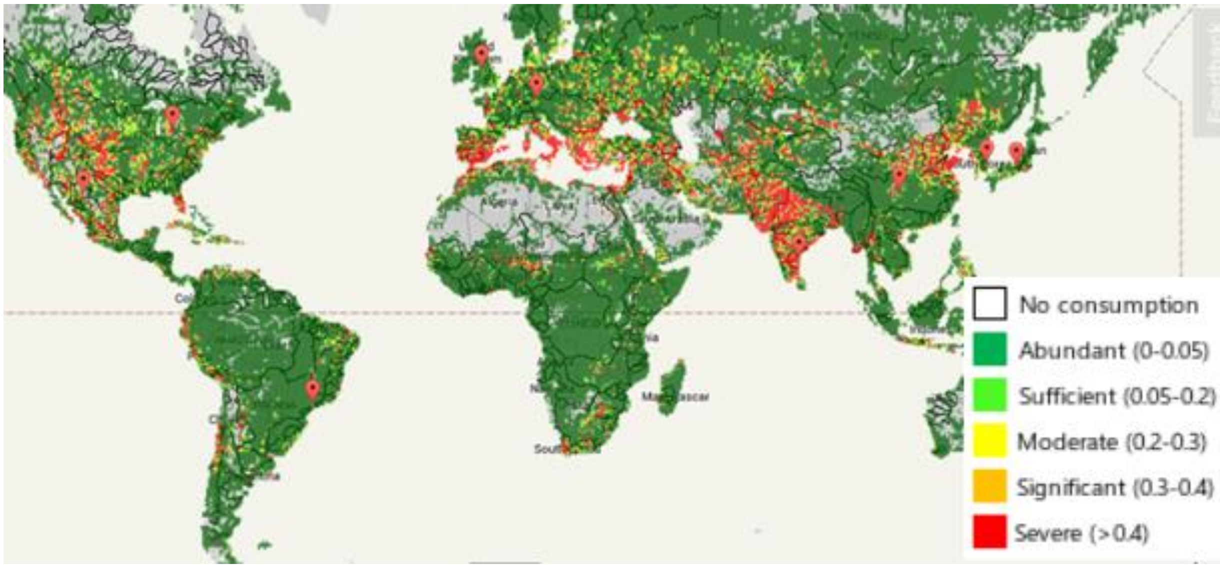


Figure 73 WRF Maximum Water Stress with HAC Facilities

6.4 Chapter 6 Summary

Companies or organizations can use the results of the WRF's analysis in much the same way that the GWT results can be useful. First, facilities that are found to be in stressed locations can be prioritized for water-saving investments such as water recycling. Second, the projections can be used for planning future expansions and help the decision makers to avoid potentially stressed water supplies. The WRF Climate Change metric can potentially be even more useful than the GWT projections because it takes economics, climate change and mitigation, and population into account.

One ambiguous issue with the WRF is the 'Stress' and 'Scarcity' definitions. In the GWT (and other sources), 'Stress' typically follows the Falkenmark index or a similar 'water available scaled to population' equation. However, for the WRF it is the consumption divided by the available water in a particular location. Interestingly, the WRF metric for Scarcity follows the same equation, but from a different database.

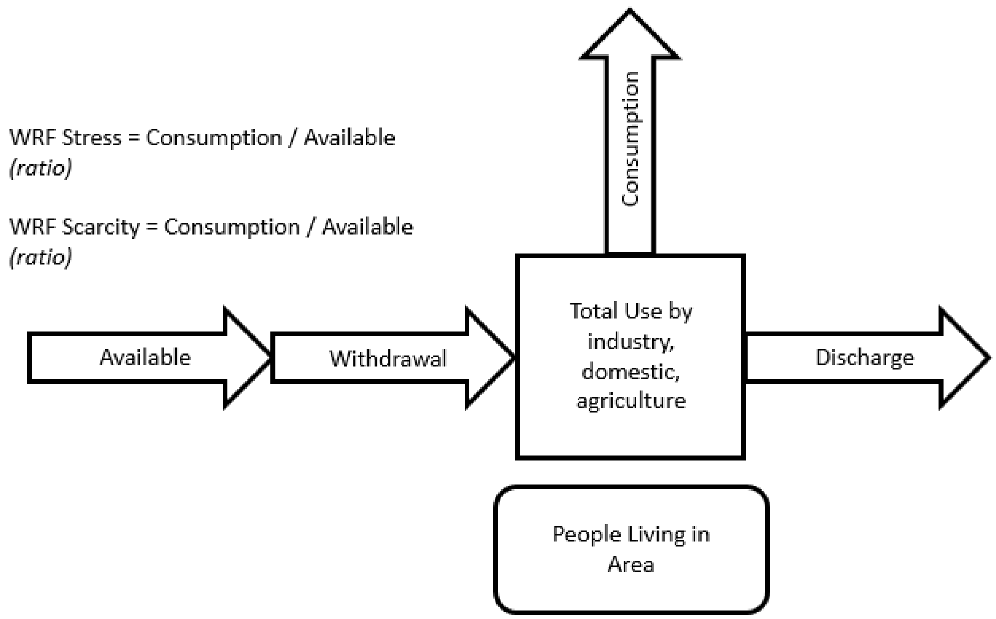


Figure 74 WRF Stress and Scarcity Definitions Graphic

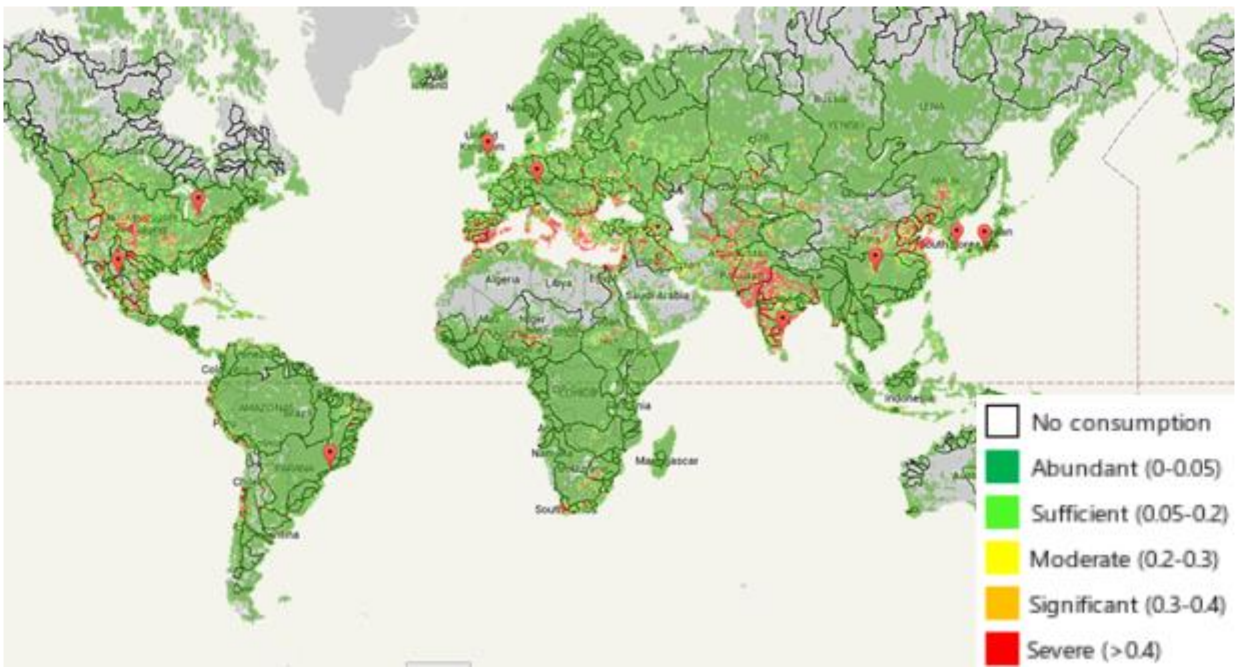


Figure 75 WRF Water Stress (GLOWASIS) Annual Average

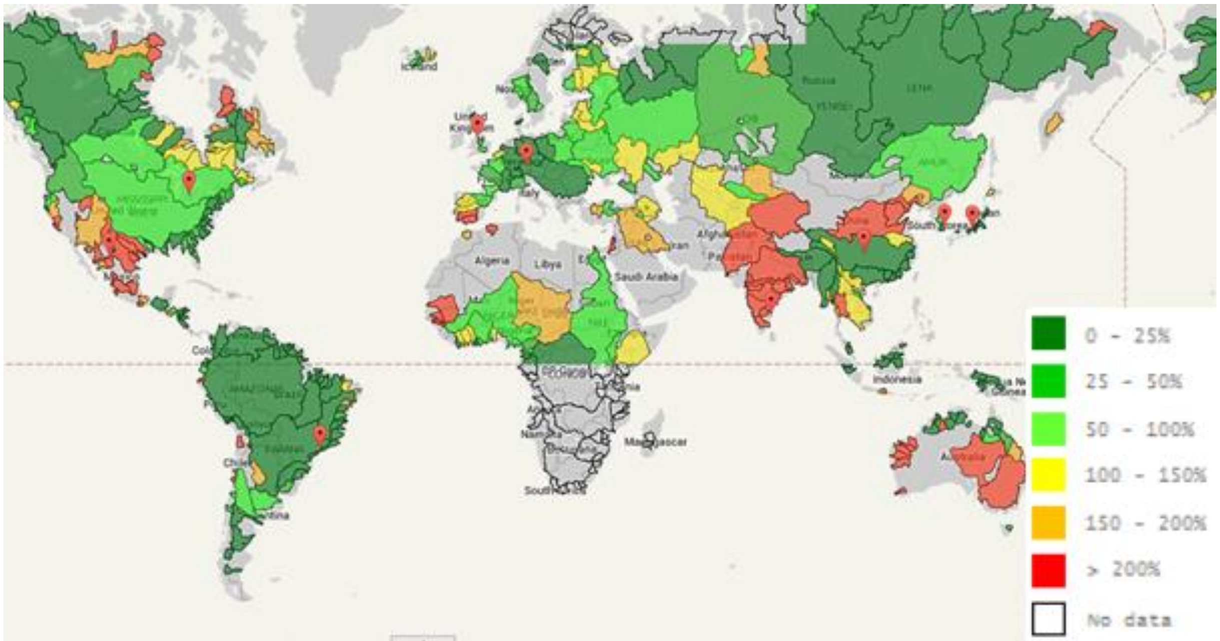


Figure 76 WRF Water Scarcity (WFN) Annual Average

Once it is understood exactly what the tool results are and how the tool arrived at the output the results can be useful. Having an in depth understanding of the water profile and examining the results can help an organization understand their water risks and stresses. According to Schornagela, understanding the exact local water situation is critical (Joost Schornagela, 2012). The more localized results are more likely to give good guidance on the exact water situation at a location. One the facilities risk metrics are understood an organization can take steps to alleviate that risk by reducing use, shifting locations, or changing water strategy. For the HAC, the WRF found that the locations with the highest stress and risk were located in Brazil, China, Mexico, and India. Additionally, all of the facilities were listed as ‘Some Risk’ with the exception of the facilities in Germany. This means that the user of the WRF may need to re-weight the metrics to align with what concerns the company most. For example, the company may prioritize floods and droughts. With the risks recalculated, that may result in a different risk profile for the entire organization. Armed with this information, the HAC executives could now take steps to reduce that risk and potentially help the company.

CHAPTER 7 AQUEDUCT ANALYSIS OF HYPOTHETICAL AUTOMOTIVE COMPANY

7.1 Aqueduct Approach

Aqueduct takes a different approach than the GWT or WRF. Aqueduct's general usage plan is covered in Figure 6, and begins with the collection of GPS or address information for the facilities. This will be the only input that Aqueduct uses. Once the locations are input, Aqueduct allows the user to have a great deal of customization of weights and water metrics within the tool. For example, a metric such as Flood Risk can be isolated or given more weight in the overall risk. The results are all mapped within the tool in a browser, but can be output to an Excel file. However, similar to the WRF, AQE is an online that *may* be updated at any time. The results for AQE for this thesis are from the period of July 2014 to February 2015. Results from a current iteration of the tool *may* be different from the results in this thesis. The World Resource Institute, who created and maintains Aqueduct, summarizes it as follows:

"(T)he Aqueduct Water Risk Atlas provides comparability across the globe acting to highlight areas of potential concern. These global metrics and associated maps can help identify water-related risks, and provide a picture of how they vary spatially across regions, countries, or continents. However, to understand the complete picture of the conditions on the ground, further study must evaluate each area's infrastructure and policy and management practices that might mitigate the identified water-related risks." (Paul Reig, 2013)

Table 22 shows the HAC information Aqueduct needs. The water usage information is not needed for Aqueduct to give results. To begin using Aqueduct, it is important to understand that the entire tool is located online (http://www.wri.org/our-work/project/aqueduct) and is accessed through a browser. This is important for a few reasons. First, the tool cannot be downloaded and stored, so when the tool is updated it may give different results than were output previously. Second, the facilities have to be reloaded on every use.

7.1.1 Aqueduct Input

Inputting facilities is straightforward. They can be entered either individually or in a batch from an Excel file. Once the HAC's facilities are uploaded, Aqueduct immediately has their water metrics and no macro or script needs to be run.

Table 22 HAC Aqueduct Input

Name	Latitude	Longitude
USA Car	42.5	-83.4
USA Truck	42.5	-83.4
India Car	13.1	80.27
India Truck	13.1	80.27
Germany Car	48.13	11.56
Mexico Car	28.64	-106.1
China Car	29.67	106.53
China Truck	29.67	106.5
Japan Car	35.18	136.9
Japan Truck	35.18	136.9
South Korea Car	35.6	129.3
Brazil Car	-23.6	-46.6
Brazil Truck	-23.6	-46.6
UK Luxury Car	53.099	-2.44
Germany Engine	48.13	11.56
Brazil Transmission	-23.6	-46.6

7.1.2 Aqueduct Metrics and Weights

Aqueduct, similar to GWT and WRF, has a variety of water metrics that are available for output. Similar to WRF, Aqueduct can take all of them into account and give an overall water risk assessment. To understand exactly what this entails, it is useful to understand what data Aqueduct possesses. Another feature that Aqueduct shares with the WRF (and that the GWT does not have) is the ability to weight different risk metrics according to how important they are to the user. There are default values for different industries, and they can all be adjusted.

The Overall Water Risk calculated by the tool is outlined in Figure 77. Essentially, every metric that Aqueduct calculates (all are shown in Figure 77) for a location is included in a weighted fashion to calculate the Overall Water Risk. Aqueduct has a default setting for the weights of the metrics, but there are sets of weights based on industry as well.

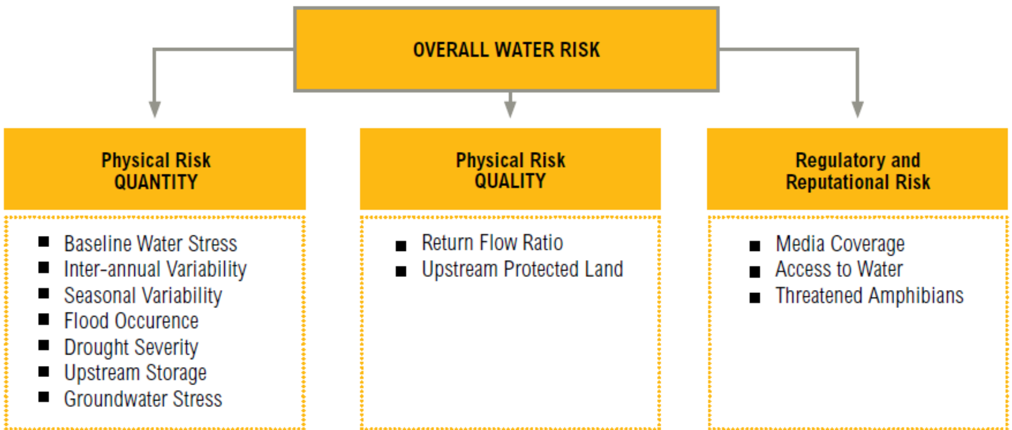


Figure 77 Aqueduct Water Metrics

From WRI: "The Aqueduct Water Risk Atlas offers 10 preset indicator weighting profiles. These profiles were developed based on information provided in corporate water disclosure initiatives and input from water experts to reflect the particular risks and challenges faced by each water intensive industry sector." (Paul Reig, 2013) WRI's ten default weight profiles are shown in Figure 78. The weights in Aqueduct are also exponential as shown in Figure 79. The Overall Water Risk map with HAC facilities plotted is shown in Figure 80. For the purposes of this thesis, the default weights will be left. The HAC does not truly fit any industry that has an available preset weight profile.

WEIGHTING PROFILES	
Default	Agriculture
Food & Beverage	Chemicals
Electric power	Semiconductor
Oil & Gas	Mining
Construction materials	Textile

Figure 78 WRI's Preset Industry Weight Profiles (Paul Reig, 2013)

IMPORTANCE	EXPONENT	WEIGHT
Very low	2^0	1
Low	2^1	2
Medium	2^2	4
High	2^3	8
Very high	2^4	16

Figure 79 Aqueduct Weight Factors (Paul Reig, 2013)

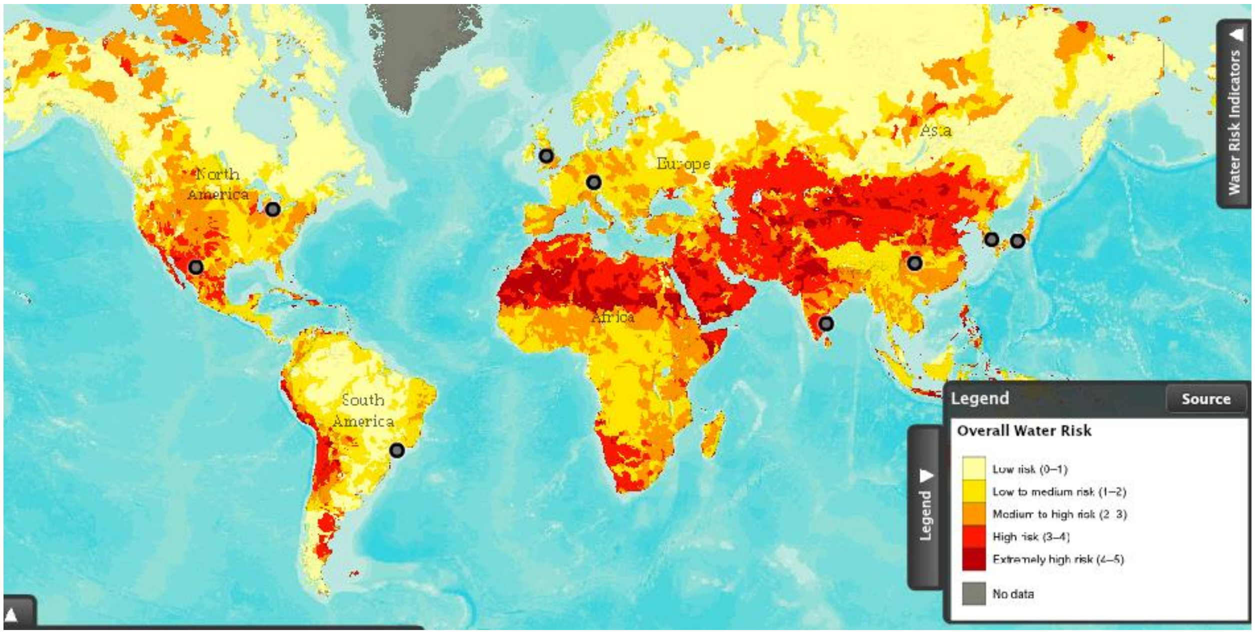


Figure 80 Overall Water Risk from AQE for HAC facilities shown as black circles

7.1.3 Aqueduct Equation for Water Stress/Scarcity

Aqueduct uses a similar principle to calculate it's version of stress/scarcity as the GWT UNH Scarcity metric. The equation for calculating the Baseline Water Stress throughout the tool (there are two versions, one included in the Overall Risk and one used for the Projected Change calculations) follows the principle of a ratio calculating the relationship between water available and water withdrawn in a given location or area, and expressing that as a percentage. The equation is shown in Equation 5 and the map of BWS is shown in Figure 81.

Equation 5 Aqueduct Calculation of BWS

$$BWS = \frac{Total\ Annual\ WIthdrawals}{Total\ Annual\ Available}\ [\%]$$

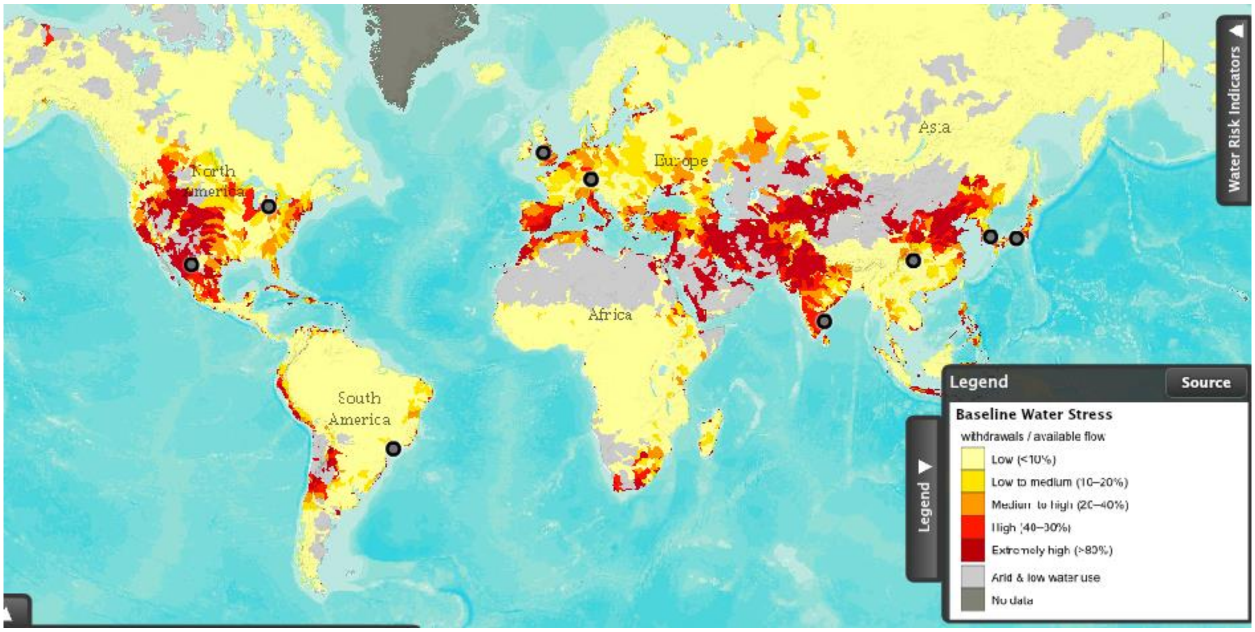


Figure 81 AQE BWS metric plotted globally with HAC facilities plotted as black circles

7.2 Aqueduct Results for the HAC

Aqueduct outputs results in the same manner as the WRF with the exception that it does not give an overall risk profile of the entire company (Risk Portfolio in WRF). Despite that, Aqueduct allows for mapping of the metrics in any combination, and has an output of all the results in an Excel file.

Most of the metrics in Aqueduct are similar to previously discusses metrics (Flood Occurrence) or are intuitive as to their meaning (Drought Severity). Some of the metrics are less intuitive. For example, the Baseline Water Stress (BWS) in Aqueduct is different from the other tools stress metrics. In Aqueduct, the BWS is a ratio of total withdrawal in an area divided by the total water available. This information comes from WRI, FAO AquaStat, and NASA (Paul Reig, 2013). A metric that the other tools do not have is Return Flow Ratio (RFR). RFR is ratio of water that has previously been used and discharged back into the water supply. Equation 6 gives the exact calculation. Essentially, the higher the ratio the more dependent the water supply is on infrastructure to treat the water if it has been withdrawn previously. Another unique metric is the Upstream Protected Land (UPL). Although the other tools have some protected land information, GWT and WRF just indicate which areas those are. The UPL is a measure of the percentage of water that originates in a protected area. The general idea is that the more water that comes from protected areas, the better the water quality will generally be (WRI, 2014).

Equation 6 Return Flow Ratio

$$Return\ Flow\ Ratio = \frac{Total\ Available - Consumption}{Total\ Available}$$

7.2.1 Aqueduct Individual Facility Results

Aqueduct essentially has two outputs, and one is an Excel workbook of all of the metrics for each facility. Aqueduct does output the raw values for all of the metrics as well as the weights assigned. All of the HAC results are shown in Table 23. All of the metrics follow a 5-category scale, with lower values corresponding with lower risk or stress. In order to examine the results from Aqueduct, one facility will be examined in detail: India Car.

7.2.2 India Car Results

India Car is assigned an Overall Water Risk of ‘High Risk’ by Aqueduct. To understand why, it is important to begin with the way Aqueduct assigns a risk score. In Figure 77 the way in which the metrics are taken into account are graphically explained. Essentially, there are three main categories of risk that are taken into account for the Overall Water Risk, they are: Overall Physical Risk Quantity, Overall Physical Risk Quality, and Overall Regulatory & Reputational Risk. These categories’ scores are calculated by weighing each of the individual metrics calculated by the databases in the tool.

For the default weighing scheme used in this thesis, the metrics of ‘High’ or ‘Very High’ importance are: BWS, Upstream Storage, Groundwater Stress (GS), and Access to Water (AW). All four of these metric relate directly to the availability of water. (WRI, 2014) The other water metrics still affect the result, but because the weighing scheme is exponential, those four have a much larger impact. For the India Car location: BWS is rated as ‘Very High Risk’, Upstream Storage is ‘No major reservoirs’, GS is ‘Low to Medium’, and AW is ‘Medium to High’. These values are fairly high stress and are the main contributors to the Overall Water Risk score of ‘High’.

The other metrics relating to access to water are medium and can still have a significant impact on the Overall Risk. For example, Inter-Annual Variability, Flood Occurrence, and Drought Severity are all weighed as ‘Medium’. The other metric that is rated at ‘Medium’ is Media Coverage. The metrics with a ‘Low’ weight are 8x less impactful than the ‘Very High’ metric (BWS) and 4x less impactful than ‘High’ metrics (Inter-Annual Variability, Flood Occurrence, and Drought Severity).

The India Car facility’s risks are primarily from the BWS, UPL, Seasonal Variability, and Flood Occurrence. The RFR is also ‘High’, and varieties of other risks are in ‘Medium to high’, which can each be cause for concern. From the Aqueduct analysis of the India Car facility, it is at a high risk for water availability, especially basic access to water to operate.

Table 23 Aqueduct Results for HAC

	Weights		Very High (4x)	Medium (1x)	Low (0.5x)	Medium (1x)	Medium (1x)	High (2x)
Location Title	Overall Water Risk	Overall Physical Risk QUANTITY	Baseline Water Stress	Inter-annual Variability	Seasonal Variability	Flood Occurrence	Drought Severity	Upstream Storage
USA Car	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	1. Low (<10%)	2. Low to medium (0.25-0.5)	2. Low to medium (0.33-0.66)	3. Medium to high (4-9)	2. Low to medium (20-30)	3. Medium to low (0.5-0.25)
USA Truck	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	1. Low (<10%)	2. Low to medium (0.25-0.5)	2. Low to medium (0.33-0.66)	3. Medium to high (4-9)	2. Low to medium (20-30)	3. Medium to low (0.5-0.25)
India Car	4. High risk (3-4)	4. High risk (3-4)	5. Extremely high (>80%)	2. Low to medium (0.25-0.5)	4. High (1.0-1.33)	4. High (10-27)	2. Low to medium (20-30)	No major reservoirs
India Truck	4. High risk (3-4)	4. High risk (3-4)	5. Extremely high (>80%)	2. Low to medium (0.25-0.5)	4. High (1.0-1.33)	4. High (10-27)	2. Low to medium (20-30)	No major reservoirs
Germany Car	3. Medium to high risk (2-3)	3. Medium to high risk (2-3)	3. Medium to high (20-40%)	2. Low to medium (0.25-0.5)	1. Low (<0.33)	4. High (10-27)	2. Low to medium (20-30)	5. Extremely low (<0.12)
Mexico Car	3. Medium to high risk (2-3)	3. Medium to high risk (2-3)	5. Extremely high (>80%)	4. High (0.75-1.0)	3. Medium to high (0.66-1.0)	3. Medium to high (4-9)	3. Medium to high (30-40)	1. High (>1)
China Car	3. Medium to high risk (2-3)	2. Low to medium risk (1-2)	1. Low (<10%)	2. Low to medium (0.25-0.5)	3. Medium to high (0.66-1.0)	4. High (10-27)	2. Low to medium (20-30)	4. Low (0.25-0.12)
China Truck	3. Medium to high risk (2-3)	2. Low to medium risk (1-2)	1. Low (<10%)	2. Low to medium (0.25-0.5)	3. Medium to high (0.66-1.0)	4. High (10-27)	2. Low to medium (20-30)	4. Low (0.25-0.12)
Japan Car	3. Medium to high risk (2-3)	4. High risk (3-4)	4. High (40-80%)	2. Low to medium (0.25-0.5)	2. Low to medium (0.33-0.66)	4. High (10-27)	2. Low to medium (20-30)	5. Extremely low (<0.12)
Japan Truck	3. Medium to high risk (2-3)	4. High risk (3-4)	4. High (40-80%)	2. Low to medium (0.25-0.5)	2. Low to medium (0.33-0.66)	4. High (10-27)	2. Low to medium (20-30)	5. Extremely low (<0.12)
South Korea Car	4. High risk (3-4)	4. High risk (3-4)	5. Extremely high (>80%)	2. Low to medium (0.25-0.5)	4. High (1.0-1.33)	3. Medium to high (4-9)	1. Low (<20)	No major reservoirs
Brazil Car	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	2. Low to medium (10-20%)	2. Low to medium (0.25-0.5)	3. Medium to high (0.66-1.0)	4. High (10-27)	2. Low to medium (20-30)	2. High to medium (1-0.5)
Brazil Truck	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	2. Low to medium (10-20%)	2. Low to medium (0.25-0.5)	3. Medium to high (0.66-1.0)	4. High (10-27)	2. Low to medium (20-30)	2. High to medium (1-0.5)
UK Luxury Car	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	2. Low to medium (10-20%)	1. Low (<0.25)	2. Low to medium (0.33-0.66)	4. High (10-27)	2. Low to medium (20-30)	No major reservoirs
Germany Engine	3. Medium to high risk (2-3)	3. Medium to high risk (2-3)	3. Medium to high (20-40%)	2. Low to medium (0.25-0.5)	1. Low (<0.33)	4. High (10-27)	2. Low to medium (20-30)	5. Extremely low (<0.12)
Brazil Transmission	2. Low to medium risk (1-2)	2. Low to medium risk (1-2)	2. Low to medium (10-20%)	2. Low to medium (0.25-0.5)	3. Medium to high (0.66-1.0)	4. High (10-27)	2. Low to medium (20-30)	2. High to medium (1-0.5)

	High (2x)		Medium (1x)	Low (0.5x)		Medium (1x)	High (2x)	Low (0.5x)
Location Title	Groundwater Stress	Overall Physical Risk QUALITY	Return Flow Ratio	Upstream Protected Land	Overall Regulatory & Reputational Risk	Media Coverage	Access to Water	Threatened Amphibians
USA Car	No data	4. High risk (3-4)	3. Medium to high (20-40%)	5. Extremely low (<5%)	1. Low risk (0-1)	3. Medium to high (0.1-0	1. Low (<2%)	1. Low (0%)
USA Truck	No data	4. High risk (3-4)	3. Medium to high (20-40%)	5. Extremely low (<5%)	1. Low risk (0-1)	3. Medium to high (0.1-0	1. Low (<2%)	1. Low (0%)
India Car	2. Low to medium (1-5)	5. Extremely high risk (4-5)	4. High (40-80%)	5. Extremely low (<5%)	3. Medium to high risk (2-3)	2. Low to medium (0.05-	3. Medium to high (5-10%)	1. Low (0%)
India Truck	2. Low to medium (1-5)	5. Extremely high risk (4-5)	4. High (40-80%)	5. Extremely low (<5%)	3. Medium to high risk (2-3)	2. Low to medium (0.05-	3. Medium to high (5-10%)	1. Low (0%)
Germany Car	2. Low to medium (1-5)	3. Medium to high risk (2-3)	3. Medium to high (20-40%)	4. Low (10-5%)	1. Low risk (0-1)	1. Low (<0.05%)	1. Low (<2%)	1. Low (0%)
Mexico Car	No data	4. High risk (3-4)	3. Medium to high (20-40%)	5. Extremely low (<5%)	2. Low to medium risk (1-2)	2. Low to medium (0.05-	2. Low to medium (2-5%)	4. High (15-35%)
China Car	No data	3. Medium to high risk (2-3)	2. Low to medium (10-20%)	5. Extremely low (<5%)	3. Medium to high risk (2-3)	2. Low to medium (0.05-	3. Medium to high (5-10%)	3. Medium to high (5-15%)
China Truck	No data	3. Medium to high risk (2-3)	2. Low to medium (10-20%)	5. Extremely low (<5%)	3. Medium to high risk (2-3)	2. Low to medium (0.05-	3. Medium to high (5-10%)	3. Medium to high (5-15%)
Japan Car	No data	4. High risk (3-4)	4. High (40-80%)	5. Extremely low (<5%)	1. Low risk (0-1)	1. Low (<0.05%)	1. Low (<2%)	1. Low (0%)
Japan Truck	No data	4. High risk (3-4)	4. High (40-80%)	5. Extremely low (<5%)	1. Low risk (0-1)	1. Low (<0.05%)	1. Low (<2%)	1. Low (0%)
South Korea Car	No data	No data	5. Extremely high (>80%)	5. Extremely low (<5%)	1. Low risk (0-1)	1. Low (<0.05%)	1. Low (<2%)	1. Low (0%)
Brazil Car	No data	3. Medium to high risk (2-3)	1. Low (<10%)	5. Extremely low (<5%)	2. Low to medium risk (1-2)	3. Medium to high (0.1-0	1. Low (<2%)	2. Low to medium (1-5%)
Brazil Truck	No data	3. Medium to high risk (2-3)	1. Low (<10%)	5. Extremely low (<5%)	2. Low to medium risk (1-2)	3. Medium to high (0.1-0	1. Low (<2%)	2. Low to medium (1-5%)
UK Luxury Car	No data	3. Medium to high risk (2-3)	2. Low to medium (10-20%)	5. Extremely low (<5%)	2. Low to medium risk (1-2)	5. Extremely high (0.4-0	1. Low (<2%)	1. Low (0%)
Germany Engine	2. Low to medium (1-5)	3. Medium to high risk (2-3)	3. Medium to high (20-40%)	4. Low (10-5%)	1. Low risk (0-1)	1. Low (<0.05%)	1. Low (<2%)	1. Low (0%)
Brazil Transmission	No data	3. Medium to high risk (2-3)	1. Low (<10%)	5. Extremely low (<5%)	2. Low to medium risk (1-2)	3. Medium to high (0.1-0	1. Low (<2%)	2. Low to medium (1-5%)

7.2.3 Aqueduct Projections

Aqueduct has a much different way of handling projections than the other two tools. As a reminder, the GWT had a projection for its TRWR and ARWS, but those projections only took into account population changes (WBCSD, 2011b). Additionally, the WRF had a metric for Climate Change, but that metric was essentially a measure of how a country would handle changes according to the A2 IPCC Scenario for 2050 (WWF, 2014a). Aqueduct's projection is similar in principle to the GWT projection in that it projects a metric of water stress. However, it projects the change relative to the original value, and the projection can be tailored to a variety of time-scales and IPCC scenarios (WRI, 2014).

According to WRI: "These maps (and exported results) show projected change in baseline water stress, Aqueduct's measure of competition for limited water resources. They were originally published on Aqueduct in 2011. These older maps use water withdrawal data from the year 2000, which the maps in the Risk Atlas use withdrawal data from 2010. The projected change in baseline water stress is based on three different scenarios of climate change and socio-economic development created by the IPCC: the A2, A1B, and B1 scenario." (WRI, 2014) For an overview of the exact parameters around the projection, consult *Freshwater Sustainability Analyses: Interpretive Guidelines* by ISciences and Coca-Cola (ISciences, 2011).

The results from the projection of BWS are significantly different from other water metric covered in this thesis. Most metrics typically follow the pattern of taken a calculated value and assigning it a relative risk or stress state score. The projection of BWS in Aqueduct is very specific in the conditions that are projected to exist. Table 24 is the complete list of possible results for the projected change in BWS for Aqueduct.

It is important to note that all of the projection maps are changes to the BWS in that location according to the original BWS stress state. For example, on the projection map both USA Car and Japan Car are listed as ‘Near Normal Conditions’. However, since Japan Car’s BWS is ‘Moderate Stress’ it is still in that higher stress state. Additionally, none of the plots can collect the entire key for the maps, so Table 24 serves as the key for all of the projections (colors and hash marks both match).

All of the projection and BWS results from Aqueduct for the HAC are in Table 25. The main points are that South Korea Car is actually projected to have an improving water stress state for both the B1 and AB1 scenarios, and near normal conditions for scenario A2. Facilities in Brazil, China, and India are projected to have a worsening BWS for almost all IPC scenarios and time scales, with the exception being India for the B1 scenario.

Table 24 Projected Change States for Aqueduct BWS Projections (ISciences, 2011) [Serves as key for all projection maps from AQE]

Projected Change in Water Stress Category	Description
Exceptionally Less Stressed	Water stress is less than 0.125 times that during baseline conditions. Competition for freshwater resources has decreased dramatically.
Extremely Less Stressed	Water stress is 0.357-0.125 times that during baseline conditions. Competition for freshwater has decreased substantially.
Significantly Less Stressed	Water stress is 0.357–0.500 times that during baseline conditions. Competition for freshwater has decreased significantly.
Moderately Less Stressed	Water stress is 0.500-0.588 times that during baseline conditions. There has been a moderate decrease in competition for freshwater resources.
Wetter but still Extremely High Stress	Water stress is less than 0.588 times that during baseline conditions, but resulting water stress levels are still extremely high.
Near Normal Conditions	Water stress levels are within the range of expected variation and do not pose any significant added risk or benefit.
Drier but still Low Stress	Conditions are over 1.7 times more stressed than baseline, but do not pose a significant problem for households, industry, or irrigated agriculture because such use accounts for a very small fraction of the available supply. Rain-fed agriculture may experience some difficulty relative to baseline conditions.
Moderately More Stressed	Conditions are 1.7–2.0 times more stressed than baseline. Planning agencies may consider adaption measures including new restrictions on discretionary water uses and investments in infrastructure.
Severely More Stressed	Conditions are 2.0–2.8 times more stressed than baseline. Awareness of looming increases in water stress should be widespread. Planning agencies should actively consider adaption measures and associated investments. Without sufficient investment, communities may face new restrictions on water use and/or occasional supply disruptions.
Extremely More Stressed	Conditions are 2.8–8.0 times more stressed than baseline. Looming changes in water stress should be among the foremost concerns of residents and planning agencies. Without major investment, future supply disruptions may be widespread and affect the core economy.
Exceptionally More Stressed	Conditions are more than 8.0 times more stressed than baseline. Basic services (e.g. power, drinking water distribution) are likely at risk and require significant intervention and major sustained investments.
Missing Data	Unable to compute the socioeconomic drought indicator due to missing data.
Uncertainty in Direction: \\\\\\\\\\\\	The range of results across the ensemble of general circulation models includes both "more stressed" and "less stressed" categories.
Uncertainty in Magnitude: /////////	The range of results between the least and most stressed general circulation models is broad. More specifically, if each category above is normalized to span 1 unit, then, when the range of results between the least and most stressed models is greater than 1.7 units, an area has uncertainty in magnitude.

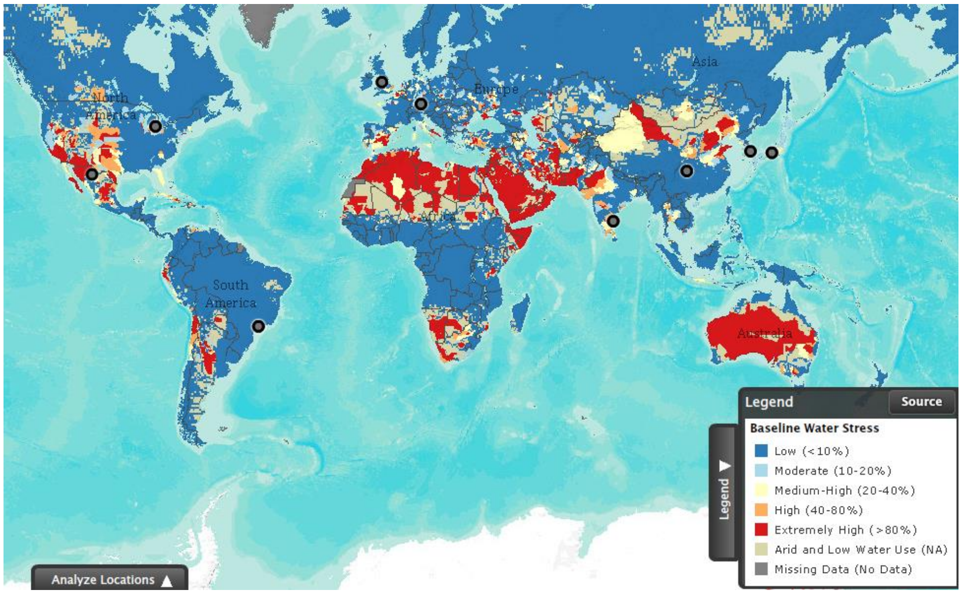


Figure 82 Aqueduct Map of BWS (Projection Baseline) HAC Facilities Plotted

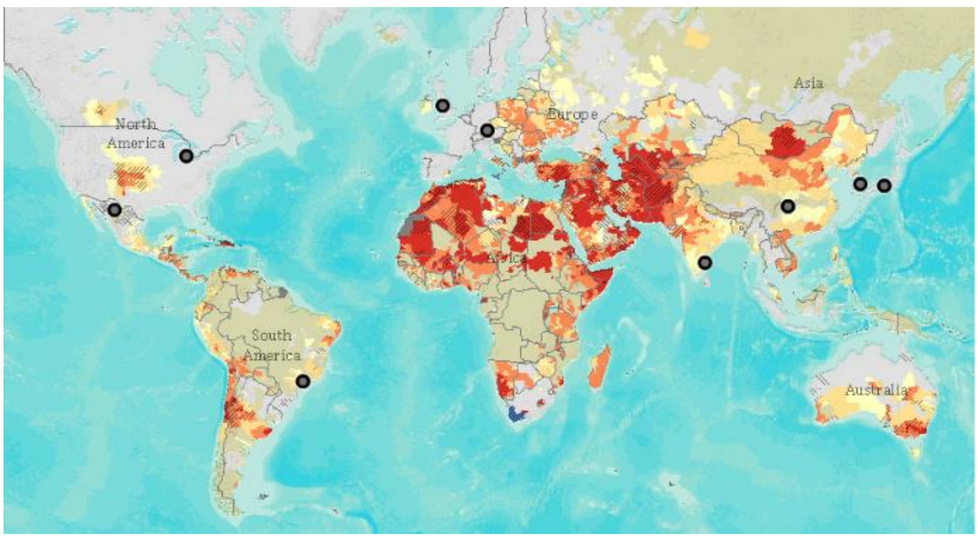


Figure 83 Aqueduct Map of Change in BWS for A2 2050 HAC Facilities Plotted (Table 24 is key)

Table 25 Projected Change in BWS and BWS Values for HAC

		Projected Change in Baseline Water Stress								
Location Title	Baseline Water Stress	2025 B1	2050 B1	2095 B1	2025 AB1	2050 AB1	2095 AB1	2025 A2	2050 A2	2095 A2
USA Car	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed
USA Truck	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed
India Car	Extremely High Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Severely More Stressed	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed	Moderately More Stressed	Moderately More Stressed
India Truck	Extremely High Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Severely More Stressed	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed	Moderately More Stressed	Moderately More Stressed
Germany Car	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
Mexico Car	Extremely High Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed
China Car	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Severely More Stressed	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed	Severely More Stressed
China Truck	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Severely More Stressed	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately More Stressed	Severely More Stressed
Japan Car	Moderate Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately Less Stressed	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
Japan Truck	Moderate Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Moderately Less Stressed	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
South Korea Car	Moderate Stress	Near Normal Conditions	Significantly Less Stresse	Significantly Less Stressed	Near Normal Conditions	Significantly Less Stressed	Extremely Less Stressed	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
Brazil Car	Low Stress	Moderately More Stressed	Moderately More Stresse	Moderately More Stressed	Severely More Stressed	Moderately More Stressed	Moderately More Stressed	Near Normal Conditions	Severely More Stressed	Extremely More Stressed
Brazil Truck	Low Stress	Moderately More Stressed	Moderately More Stresse	Moderately More Stressed	Severely More Stressed	Moderately More Stressed	Moderately More Stressed	Near Normal Conditions	Severely More Stressed	Extremely More Stressed
UK Luxury Car	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
Germany Engine	Low Stress	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions	Near Normal Conditions
Brazil Transmission	Low Stress	Moderately More Stressed	Moderately More Stresse	Moderately More Stressed	Severely More Stressed	Moderately More Stressed	Moderately More Stressed	Near Normal Conditions	Severely More Stressed	Extremely More Stressed

7.2.4 Baseline Water Stress Correlation

As was shown, Aqueduct contains two different BWS metrics, one for projections and a newer database for use with the Overall Water Risk. The first is the BWS that is factored into the Overall Water Risk and the other is used as a baseline for projected change of water stress change according to IPCC scenarios (WRI, 2014). In a similar fashion as the correlation calculation for the watershed and country level BWS's from the GWT, these BWS states will be compared. The reason this is a useful exercise is to show the differences in results based on essentially the same metric but for a different year of data. If the data match, then it can be inferred that the data for BWS may not change significantly over time. However, if there is a discrepancy then the BWS metric may change significantly over time.

The BWS that is included in the overall water risk is a calculation based on data from 2010 and collected by NASA, ISciences, and WRI (Paul Reig, 2013). The BWS used by the projections in Aqueduct follow the same calculation style and sources, but is an older data set based on withdrawals for 2000 (WRI, 2014).

To compare the BWS states for each facility from the different sources Table 27 shows the risk states with the value that is related to the stress state. The values will be used to calculate correlation. Table 27 is the BWS metric from both the standard Aqueduct calculation used for Overall Water risk and the BWS that is used as a baseline for the projected change in BWS for different scenarios and different time scales.

Table 26 Standard Water Stress State Ranges

1	Low Stress
2	Moderate Stress
3	Medium to High Stress
4	High Stress
5	Extremely High Stress

Table 27 Both BWS Metrics from Aqueduct (Overall and Projected Change baseline)

	Overall Calculation	Projected Change
Location Title	Baseline Water Stress	Baseline Water Stress
USA Car	1	1
USA Truck	1	1
India Car	5	5
India Truck	5	5
Germany Car	3	1
Mexico Car	5	5
China Car	1	1
China Truck	1	1
Japan Car	4	2
Japan Truck	4	2
South Korea Car	5	2
Brazil Car	2	1
Brazil Truck	2	1
UK Luxury Car	2	1
Germany Engine	3	1
Brazil Transmission	2	1

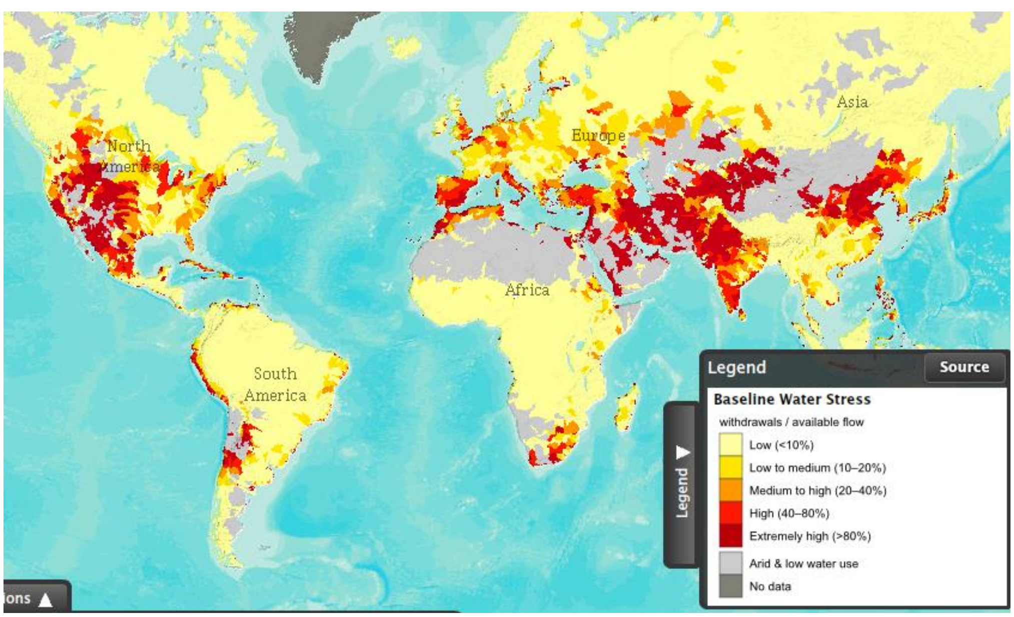


Figure 84 Aqueduct BWS used in Overall Water Risk

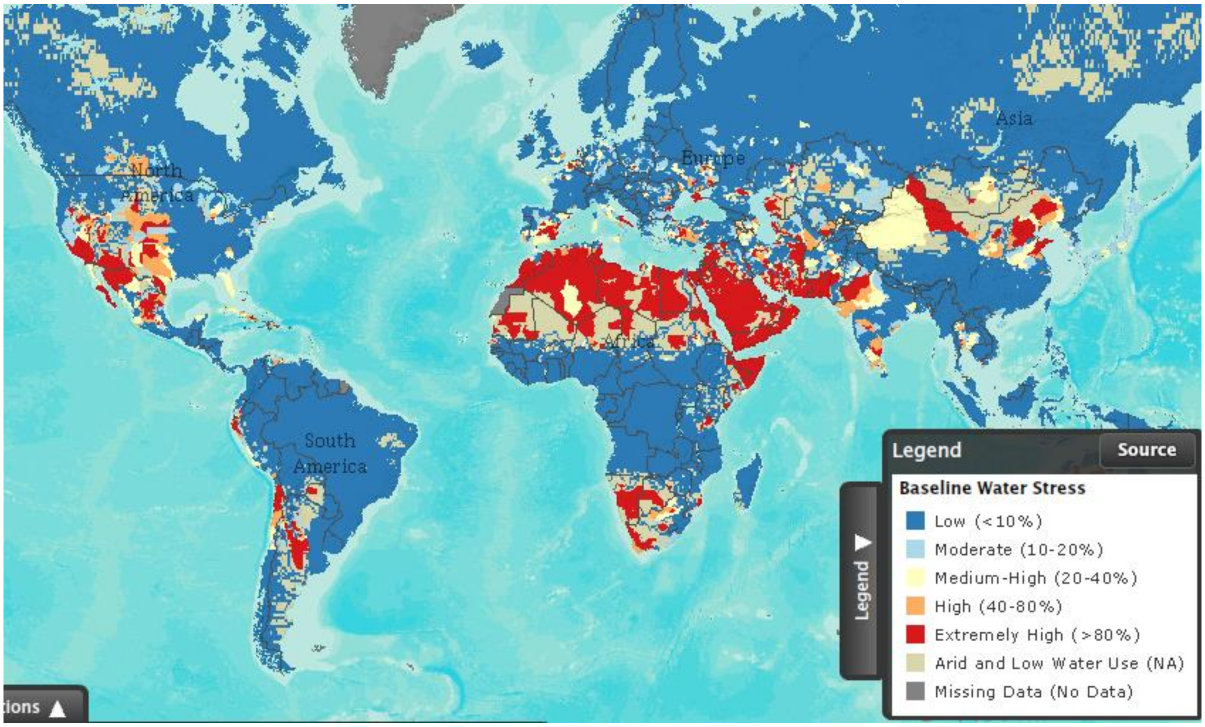


Figure 85 Aqueduct BWS used as baseline in Projected Change

7.2.5 Aqueduct Mapping of HAC Facilities

Aqueduct has the ability (unlike the other tools) to map the overall results of the tool. The Overall Water Risk calculation can be adjusted using the weights, but for the purposes of this thesis, the default weights are left. Figure 86 shows the Overall Water Risk with the HAC facility locations.

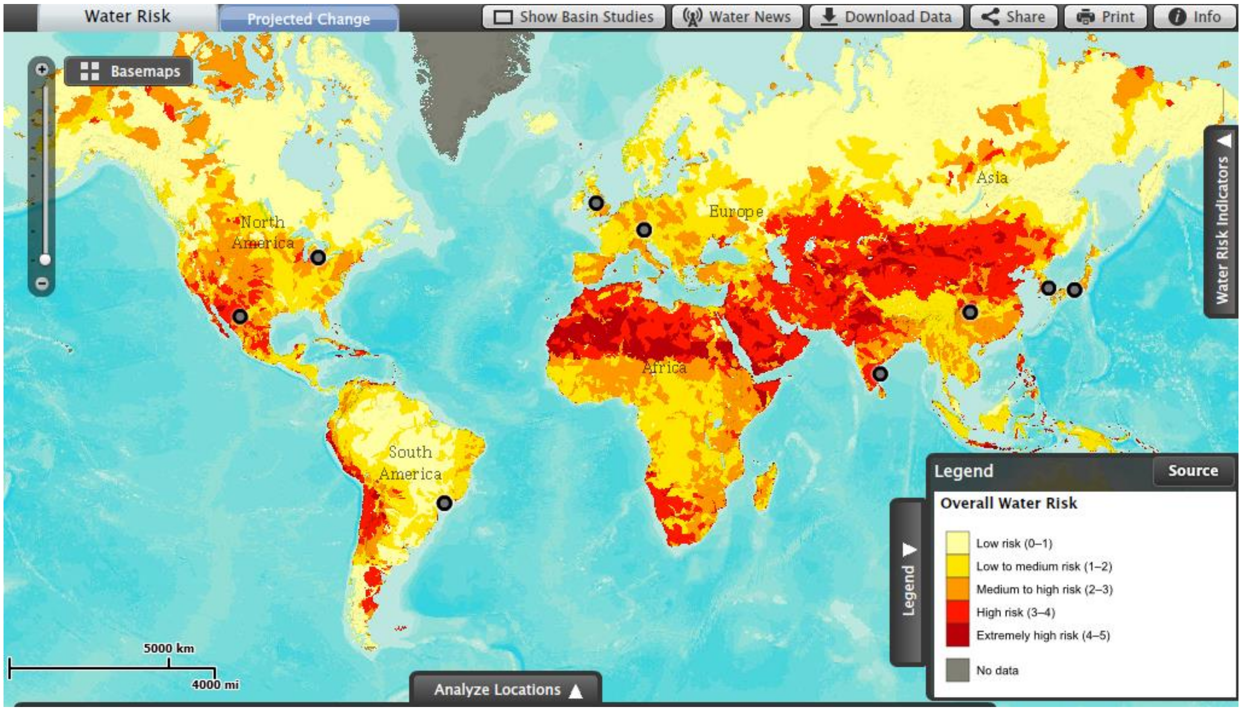


Figure 86 Aqueduct Overall Water Risk with HAC Facilities Mapped

The WRF can only plot one metric at a time, and the GWT will allow the user to plot multiple metrics, but the essentially overlay each other and do not create a comprehensive overall view of the water situation. Figure **87** shows the Flood Occurrence and Drought Severity metrics plotted together for a combined total risk. For this example, both metrics were given equal weight.

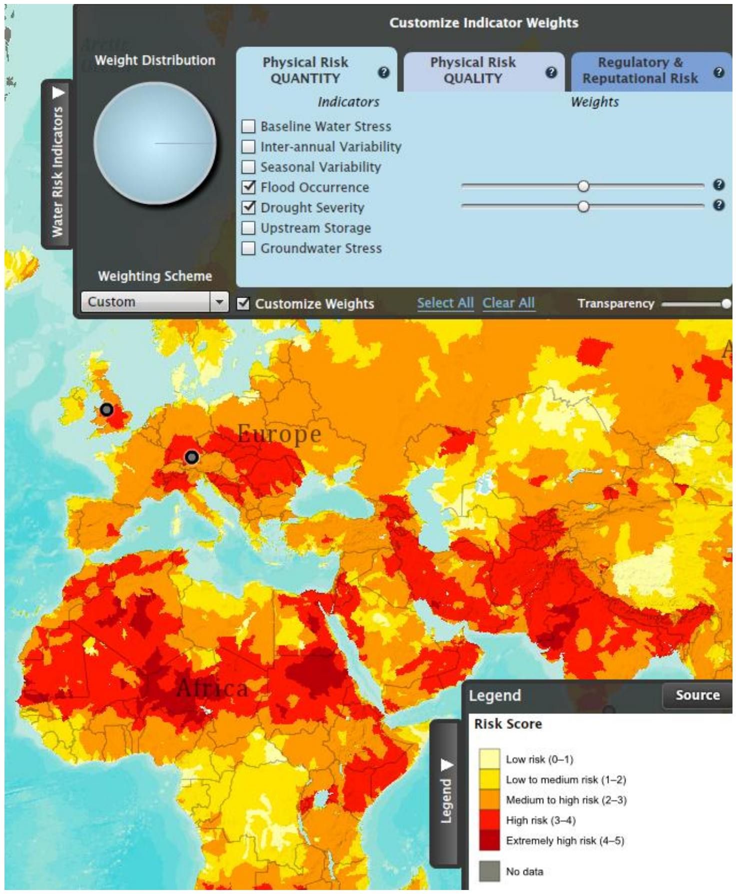


Figure 87 **Aqueduct Flood Occurrence and Drought Severity Metrics Mapped Together**

One particularly useful feature of Aqueduct is the resolution of the data, as demonstrated in Figure 88. Although there are gaps (Figure 89), when Aqueduct does have the information, it is very detailed and precise. Additionally, this high level of detail allows the user to pinpoint potentially low or high-risk locations that would have difficult to identify with either of the other two tools. Both of these maps are of the Seasonal Variability metric.

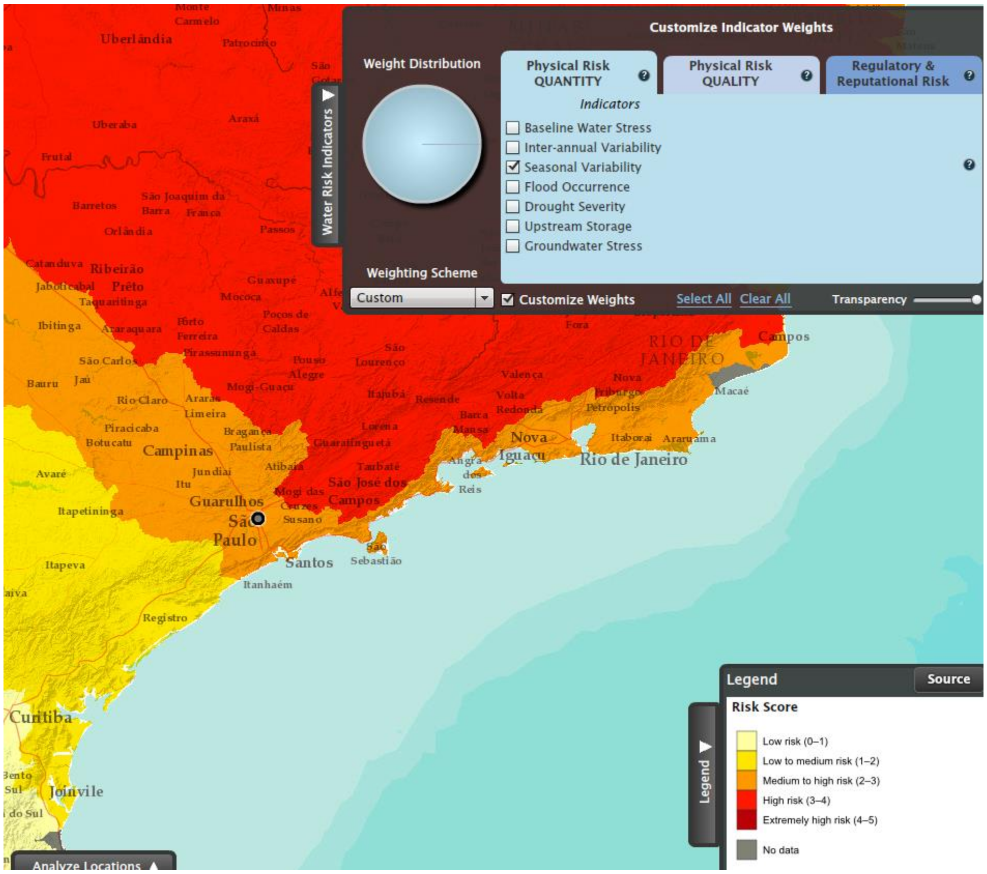


Figure 88Aqueduct Seasonal Variability metric Sãu Paulo (demonstrates resolution)

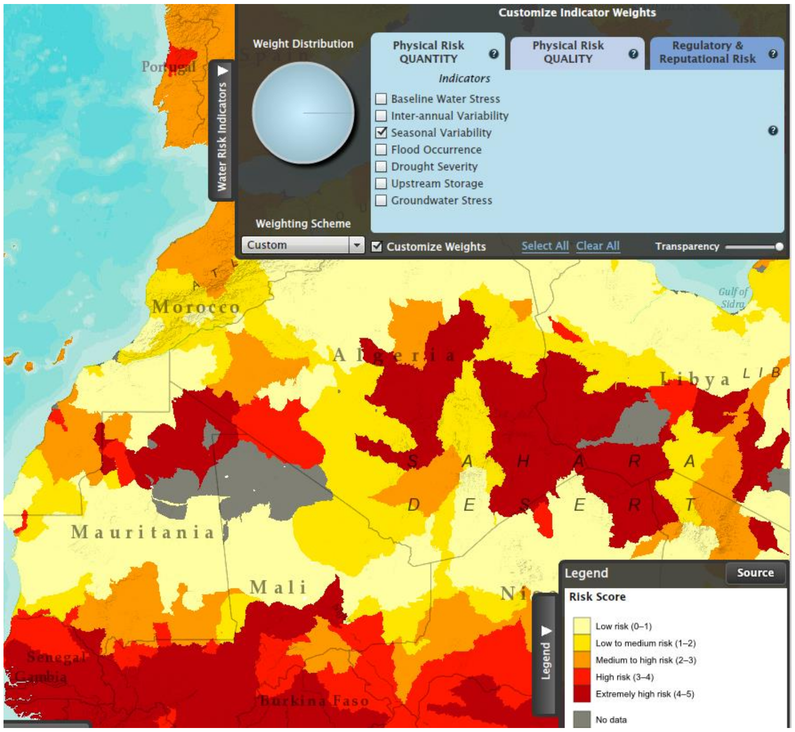


Figure 89 Aqueduct Seasonal Variability metric North Africa (demonstrates some gaps)

7.3 Chapter 7 Summary

Companies or organizations can use the results of Aqueduct analysis in much the same way that the GWT and WRF results can be useful. First, facilities that are found to be in stressed locations can be prioritized for water-saving investments such as water recycling. Second, the projections can be used for planning future expansions and help the decision makers to avoid potentially stressed water supplies. Despite the similarities, Aqueduct does provide a few unique advantages and disadvantages for the user.

The main disadvantage of Aqueduct compared to the other tools is the lack of any water accounting. The only input Aqueduct needs, or will take, is the location information of the facility and any weighing information that the user chooses to provide. The other tools do provide help with CDP and/or other disclosure operations. The other disadvantage is that there is no explicit demonstrable advantage to water-savings within the tool. The WRF and GWT at least encourage the user to know what the water use of a facility is and that number *may* affect the outcome of the tool. (Although for this thesis, the differences in water use were not substantial enough to do so.)

The main advantages of Aqueduct are: the simplicity of use, the resolution of the data, the variety of the water metrics, the ability to customize the maps and weights, and the ability to project BWS to a variety of scenarios and time scales. Aqueduct does not actually need any input in order to give the user mapped results. The input is only need to show the facilities locations on maps and to export an Excel file of the complete results. The resolution of the data in Aqueduct is much higher than the WRF or GWT. The highest resolution global dataset from the other tools is as follows: the GLOWASIS Water Stress from the WRF is at a 0.5x0.5 degree resolution

(WWF, 2015a), the GWT Scarcity UNH dataset is also at 0.5x0.5 degree (WBCSD, 2011b). For direct comparison, the BWS in Aqueduct is at a resolution of 0.125x0.125 degree (NASA, 2015). In addition, it is very simple to adjust the maps and weights in Aqueduct compared with the other tools (with the GWT not having any weights). Finally, the option to select a variety of IPCC scenarios and time scales for a projection of the BWS is simply not present in any other tool. Armed with that information, the user of the tool can quickly concentrate in on the metrics that are important for any company and analyze the risks that result from that analysis.

Aqueduct's the metrics tend to conform to more broadly accepted definitions for the water metrics. Figure 90 shows how the Aqueduct stress metric is calculated. Although this does not follow the Falkenmark index, it does follow general stress calculations from other sources such as *Water Accounting for (agro)Industrial operations and its application to energy pathways* (Joost Schornagela, 2012). The use of withdrawal for calculating stress is preferable to consumption (as is used in WRF stress) because withdrawal from a water supply is what ultimately restricts the availability for other users (Joost Schornagela, 2012).

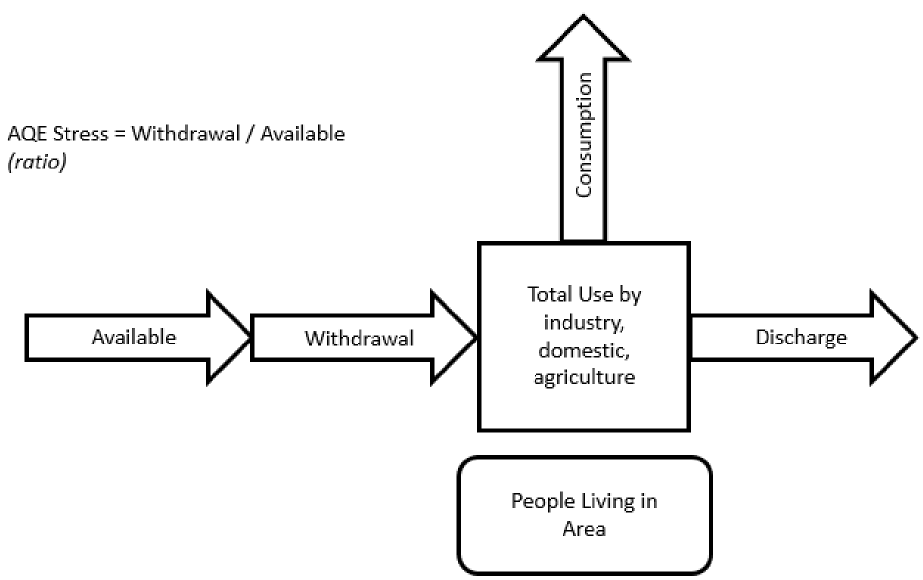


Figure 90 Aqueduct BWS Definition

Once it is understood exactly what the tool results are and how the tool arrived at the output the results can be useful. For the HAC, Aqueduct listed the facilities in India and South Korea as ‘High Risk’ and facilities in China, Germany, Japan, and Mexico as ‘Medium to High Risk’. From that high-level assessment, it is very easy to see how those facilities were given those scores. Indian, Mexican, and South Korean facilities are listed as having ‘Extremely High’ BWS’s, which can be enough because of the weight given to that metric. From the overall risk results, the HAC can prioritize risks and take steps to alleviate them.

CHAPTER 8 ANALYSIS OF KEY WATER METRICS FOR INDUSTRIAL OPERATIONS

8.1 Water Metrics that Directly Impact Operations

Water usage is important for manufacturing operations. To determine which water metrics are most applicable for the HAC or any manufacturing company, the CDP Water Report provides guidance by listing the top risk factors for industry (CDP, 2014). Figure 91 from CDP's 2014 Global Water Report (CDP, 2014) shows the top five water issues for responding companies (1,064 companies responding to CDP's Water Disclosure Request). Water stress/scarcity (the terms will both be included in this section because of the lack of specific definition by CDP) was the primary cause of disruptions, with flooding, drought, water quality, and regulatory issues being the rest. The three water tools covered in this thesis give results that are intended to aid companies in assessing water risks. However, there are conflicting conclusions from the tools. As CDP has results on these key water impacts, the usefulness of each tool can be examined in the context of matching real world results as reported to CDP. Analytically comparing the results from the tools and including results from the CDP Global Water Report will put the tools' results in context of usability for companies.

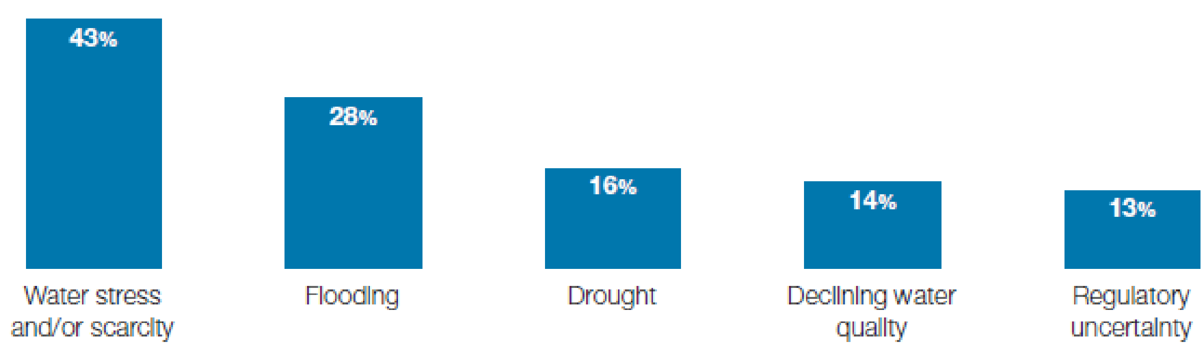


Figure 91 CDP Water 2015 Top 5 Risk Factors (% of respondents reporting issue was impacting operations) (CDP, 2014)

How can the HAC prioritize facilities' water mitigation strategies based on conflicting data? In order to answer this question, two approaches will be taken. First, an analysis of the tools' results in order to determine the level of agreement of risk/stress states or the order of ranking of risk/stress states. Finally, the CDP Global Water Report has the compiled results for the water situation of 1,064 companies worldwide (CDP, 2014), and the overlap of that survey with results from the tools can give a strong indication of which outputs are worthy of acting on. The combination of agreement analysis and comparison with current operation's water issues can give confidence and context to the key metric results from the water tools.

8.1.1 CDP Global Water Reports and Data Visualizer

CDP provides three options for examining the results of their corporate survey. First, the Global Water Report itself, which is a collection of all of the overall information but it is not detailed beyond industry sector and broad risks and stresses (CDP, 2014). Second, the CDP Global Water Results Data Visualization (CDPV), which aggregates risks and stresses for particular regions, countries, industries, exact impacts, and includes some survey information directly from responding companies (Water, 2015). This will serve as the primary backdrop for the water tools results, as it contains very detailed information for country level risks. For example, with the CDPV, it is possible to examine specifically which water issues were the top impacts affecting direct operations in Brazil, as shown in Figure 92. The third way to examine information from CDP Water is to download CDP compilations of companies responses grouped by industry. The drawback with the third approach is that CDP does not release all individual company responses publically. Despite that particular drawback, the aggregated direct operations results from CDP will be compared with the results of the three water tools and their statistical comparisons. Table 28 shows the aggregated results from the CDP Data Visualization. These are country-level and will be particularly useful for Quality and Regulatory and Reputational Risk because those metrics are based on some country-level data.

Figure 92 CDP Visualization of Brazil industrial risks to direct operations. The visualization allows for examination of the overall results, and links to specific information from company responses about water issues. (Water, 2015)

Table 28 CDP Data Visualizer Aggregated Results. The CDP Results give an X in yellow if companies reported the issue in their Direct Operations in the same country as HAC (Water, 2015)

Facility	Stress/Scarcity	Droughts	Floods	Quality	Regulatory and Reputational
USA Car	X	X	X		X
USA Truck	X	X	X		X
India Car	X		X		X
India Truck	X		X		X
Germany Car			X		
Mexico Car	X				X
China Car	X		X		X
China Truck	X		X		X
Japan Car	X		X		X
Japan Truck	X		X		X
South Korea Car					
Brazil Car	X			X	X
Brazil Truck	X			X	X
UK Luxury Car	X		X	X	
Germany Engine			X		
Brazil Transmission	X			X	X

Table 28 represents the top water issues facing companies in the reporting countries plotted onto the list of HAC facilities for easy comparison later. For example, the Flood Occurrence results can be listed next to the CDP Floods list of HAC facilities and the similarity or difference will be easy to spot. Although this information is as geographically detailed as watershed or pixel resolution data, it is still useful to compare these tables with the results of the tools. For example, if the tools do not report at least some elevated level of flood risk in Germany, than the results from the tools may not reflect the reality. These tables and individual company responses will be used to gauge whether the results of the tools appear to be effective in the following sections. It should be noted that the values of survey respondents is not what is important from CDP, just that companies reported that issue was significant in that country.

CDP also provide by-industry aggregated company responses for the water responses for specific watersheds (Analytics, 2014b). These watershed level responses are particularly useful for stress/scarcity, droughts, and floods. In Table 29, HAC facilities received an X for a specific category if a company reported that issue in the watershed in which the HAC facility is.

Table 29 CDP Data Aggregated Results. The CDP Results give an X in yellow if companies reported the issue in their Direct Operations in the same watershed as HAC

Facility	Watershed	Stress/Scarcity	Droughts	Floods	Quality	Regulatory and Reputational
USA Car	St. Lawrence	X		X		X
USA Truck	St. Lawrence	X		X		X
India Car	Palar	X				
India Truck	Palar	X				
Germany Car	Danube			X		
Mexico Car	Rio Grande (US)	X	X		X	
China Car	Chang Jiang	X		X		
China Truck	Chang Jiang	X		X		
Japan Car	GHAASBasin837					
Japan Truck	GHAASBasin837					
South Korea Car	GHAASBasin3854					
Brazil Car	Parana					X
Brazil Truck	Parana					X
UK Luxury Car	GHAASBasin1944					X
Germany Engine	Danube			X		
Brazil Transmission	Parana					X

The use of CDP Results is not exact, because the HAC facilities are hypothetical, but in concert with agreement analysis, conclusions can be reached about the validity of the water tools. The main drawback is that not all companies report watershed level data, so the results of this can only be effective as positive confirmation. In other words, if a company specifically mentioned a risk/stress in that country, that report can confirm the validity of a 'Moderate', 'High', or' Extremely High' risk/stress score, but it should not be said that the absence of a CDP impact shows a false positive from the tool. Essentially, if the CDP result shows a risk, then the tools should have at least a '3' for that category in that location. The lack of CDP response cannot be used to confirm or deny any particular risk. These results serve as positive identification of a risk or stress.

8.1.2 Statistical Analysis Approach

In order to compare the results of the tools, the correct analysis approach needed to be established. For the previous comparisons in this thesis, the use of Pearson's correlation coefficient was deemed sufficient to show the significant difference in what *should* have been similar results for the GWT and the difference of ten years for AQE BWS (GWT stress for watershed and country levels, AQE BWS from 2000 and 2010). However, for the remaining comparisons, more in-depth analysis is needed to understand the context of what the results are showing. The key metrics from CDP (Figure 91) are the metrics that directly affect operations of industry, and would be the metrics that provide the most motivation for mitigation. In other words, the analysis that follows would be what could motivate executives of a company to enact serious mitigation to minimize risk and stress exposure for their company, as overviewed in Figure 1 and discussed in Chapter 2.

8.1.3 Statistic Overview

The Pearson's correlation used previously in this thesis is a good indicator of agreement between two data sets (Dunn, 2005). However, there are other useful statistical analyses that can be performed to help dissect the results of the water tools. The following coefficients and calculations all reveal properties of the results that help put the results in context. Each measure reveals a characteristic of the tools' results. Whether it is agreement in state value, or the ranking of the facilities from best to worst.

Spearman Rank Coefficient (ρ)

The Spearman Rank Coefficient (ρ) can be thought of as the equivalent of the Pearson correlation, except it is based on the ranking of the data rather than the value (Conover, 1971). This is useful for the examination of water tools because the assigned state given by any metric can be thought of as a rank. For example, the BWS state of '1' means that that facility is ranked as a lower stress than a facility with a stress state of '5'. The facilities with states of '1' are ranked the same and the facilities with a stress state of '5' are as well.

Equation 7 Spearman Rank Coefficient (ρ), where d_i is the difference between a ranked set, and n is the number of sets (Conover, 1971)

$$\rho = 1 - \frac{6\sum {d_i}^2}{n(n^2-1)}$$

Goodman and Kruskal's Gamma (γ)

The Gamma (γ) statistic is equivalent to the Spearman Rank Coefficient, but is more capable of handling data that has a large number of ties. N_d is the number of pairs which rank in opposing order, N_s is the number of pairs whose ranking order matches.

Equation 8 Goodman and Kruskal's Gamma, with N_d being number of discordant ordered pairs, and N_s having pairs of same order (Conover, 1971)

$$\gamma = \frac{N_s - N_d}{N_s + N_d}$$

Kendall Tau Rank Correlation Coefficient (τ)

The Kendall tau rank correlation coefficient is a measure of the correlation of the quantities of two sets of data. In other words, it is a relation to the level of agreement between the values of two sets data.

Equation 9 Kendall Tau Rank Correlation Coefficient (τ), with C being the number of concordant pairs, D being the number of discordant pairs, and n being the number of sets

$$\tau = \frac{C - D}{\frac{1}{2}n(n-1)}$$

Kendall Coefficient of Concordance (W)

Kendall's Coefficient of Concordance (W) is a nonparametric statistic for examining the agreement among raters. It is a normalized statistic, if the value is 1, then the raters ranked the sets of data in the same order. If 0, there was no agreement.

Equation 10 R_i is the total rank given to object i (in this case the facility) by judge j (n is total facilities and m is the number of judges)

$$R_i = \sum_{j=1}^{m} r_{i,j}$$

Equation 11 Kendall's Coefficient of Concordance (W) ($\bar{R}$ is average rank)

$$W = \frac{12\sum_{i=1}^{n}(R_i - \bar{R})^2}{m^2(n^3 - n)}$$

8.2 Water Stress/Scarcity

Water stress is consistently classified as an important factor in the operations of a facility (Mueller et al., 2014) and it is a problematic metric because the tools have slightly different methods of calculating the stress. Water scarcity is a slightly more straightforward metric in that it is typically a ratio of available water and the water used, however the tools sometimes add to the confusion by handling the calculations of stress and scarcity in the same manner (Equation 4 WRF Stress or Scarcity Calculation). In this thesis, there are three different ways tools calculate stress

(Equation 1 GWT, Equation 4 WRF, and Equation 5 AQE). However, only the GWT followed the Falkenmark index, which is a known good indicator of risks to operations of an industrial facility (Herbst, 2009; Joost Schornagela, 2012; Kumar & Singh, 2005; Mueller et al., 2014). The WRF used a ratio of consumption to available water, and AQE used a ratio of withdrawal to available water. The three tools' water stress results are shown in Table 30.

Table 30 Water Stress Levels from GWT, AQE, and WRF. Each tool has a different calculation, but the result is a stress state, the legend is shown.

	GWT Watershed	Aqueduct	WRF		
Facility	Annual Renewable Water Supply per Person (WRI 1995)	Baseline Water Stress (WRI/NASA 2010)	Water Stress (GLOWASIS 2011)		
	(m3/person/year)				Stress State Legend
					1. Low
USA Car	>4,000	1. Low (<10%)	5		2. Low to Medium
USA Truck	>4,000	1. Low (<10%)	5		3. Medium to High
India Car	<500	5. Extremely high (>80	5		4. High
India Truck	<500	5. Extremely high (>80	5		5. Extremely high
Germany Car	1,700 - 4,000	3. Medium to high (20-	2		
Mexico Car	500 - 1,000	5. Extremely high (>80	1		
China Car	1,700 - 4,000	1. Low (<10%)	1		
China Truck	1,700 - 4,000	1. Low (<10%)	1		
Japan Car	>4,000	4. High (40-80%)	1		
Japan Truck	>4,000	4. High (40-80%)	1		
South Korea Car	1,700 - 4,000	5. Extremely high (>80	2		
Brazil Car	>4,000	2. Low to medium (10-	2		
Brazil Truck	>4,000	2. Low to medium (10-	2		
UK Super Luxury	<500	2. Low to medium (10-	2		
Germany Engine	1,700 - 4,000	3. Medium to high (20-	2		
Brazil Transmission	>4,000	2. Low to medium (10-	2		

8.2.1 Difference in Datasets

The results from the three tools for water stress are unfortunately not always consistent. There are a few reasons for this. First, the age of some of the data sets is an issue. For example, the watershed level ARWS (Stress) metric was based on WRI data from 1995 (WBCSD, 2011b). Most of the datasets used in AQE and the WRF are newer, from 2010 (Paul Reig, 2013) and 2011 (WWF, 2014a) respectively. Second, the resolution and geographic scales used by the tools are not consistent. AQE has the highest resolution for metrics that do not follow geographic boundaries (either watershed or country). This is covered in depth in section 7.2. Third, the tools calculate certain metrics differently, as shown in Equation 1 GWT Calculation of Water Stress, Equation 2 GWT Calculation of Water Scarcity, Equation 4 WRF Stress or Scarcity Calculation, and Equation 5 Aqueduct Calculation of BWS. Essentially, the GWT follows the Falkenmark index for water stress, which measures water available per person per year (WBCSD, 2011b), and the other tools use withdrawal (AQE) or consumption (WRF) divided by total water available (Paul Reig, 2013; WWF, 2014a).

For the HAC facilities, it is difficult to interpret these results because of the inconsistency between the tools. Quantifying the differences in stress states with standard statistical analysis of ranking and agreement will show the exact differences and allow for confidence analysis and comparison with known water issues from CDP.

8.2.2 Statistical Analysis of the Stress Results from GWT, AQE, and WRF Combined

To compare the results of all three tools, the first step is to find the facilities with which there was agreement. The results are shown with standard deviation per facility as well as Pearson Correlation Coefficient in Table 31. For the HAC, all three tools listed the India Facilities as 'Extremely Stressed'. It is reasonable to say there is a high confidence that that is indeed the case, and once the statistics are shown to completion, the results will be compared with the CDP results. Facilities in Brazil, China, and Germany have good agreement, with two tools having a similar state and one tools having a 1-level different state listed. Despite that agreement, facilities in Japan, Mexico, South Korea, UK, and USA had hugely variant stress states (as large a gap as possible for USA and Mexico). The standard deviation per facility given in GWT and AQE have a reasonable overall agreement of .495, which according to Conover is a ‘moderate’ relationship (Conover, 1971). The GWT to WRF relationship is in the ‘weak’ range, and the AQE to WRF is effectively no relationship (close to 0).

Table 31 Results of Three Tools’ Stress with Standard Deviation and Pearson Correlation (The Pierson Correlation is the measure of co-linearity, how well the values match)

	GWT Watershed	Aqueduct	WRF	Facility Standard Deviation
Facility	ARWS (WRI 1995)	BWS (WRI/NASA 2010)	Water Stress (GLOWASIS 2011)	
	[m3/person/year]	[ratio]	[ratio]	
USA Car	1	1	5	2.31
USA Truck	1	1	5	2.31
India Car	5	5	5	0.00
India Truck	5	5	5	0.00
Germany Car	2	3	2	0.58
Mexico Car	4	5	1	2.08
China Car	2	1	1	0.58
China Truck	2	1	1	0.58
Japan Car	1	4	1	1.73
Japan Truck	1	4	1	1.73
South Korea Car	2	5	2	1.73
Brazil Car	1	2	2	0.58
Brazil Truck	1	2	2	0.58
UK Super Luxury	5	2	2	1.73
Germany Engine	2	3	2	0.58
Brazil Transmission	1	2	2	0.58

Stress State Legend
1. Low
2. Low to Medium
3. Medium to High
4. High
5. Extremely high

Pearson Correlation Coefficient r for each relation

	GWT	*AQE*	*WRF*
GWT	1		
AQE	**0.495**	1	
WRF	**0.274**	**0.023**	1

Those results do give some context, but another important aspect is the ranking order and relationships between the data beyond the correlation of the values. As there are three tools being compared, the Spearman Rank ρ, Kendall τ, and Goodman and Kruskal’s γ cannot be used for comparing all three (Conover, 1971). Those three will be used for comparisons of two tools outputs at a time. The value of the Kendall Coefficient of Concordance can now be seen Table 32, because it can definitively show the overall relationship of the rankings assigned by the three tools. The W value being .115 is quite low, and definitively shows the level of disagreement between all three tools stress state results. Although the values of standard deviation do show that there is disagreement between the tools, this calculation shows the magnitude of the ranking disagreement. In order to further examine the differences, the results will be considered in pairs to allow the all of the listed statistical measures to be used.

Table 32 Kendall's Coefficient of Concordance (W) for all three tool's stress states. The value of .114 is very low (W is a value from 0-1 representing agreement of rankings) (AnalystSoft, 2010)

Kendall Coeff. of Concordance (W)	0.115	Average rank	0.0558
	Average rank	**Sum of Ranks**	**Mean**
GWT	**1.781**	**28.5**	**2.25**
AQE	**2.312**	**37**	**2.875**
WRF	**1.906**	**30.5**	**2.438**

Comparing the CDP responses of stress/scarcity to the three tools results in some agreement and disagreement, shown in Table 33. First, all the tools and CDP agree that the locations in India are have stress risks. GWT and AQE rated Mexico Car as stressed, and CDP watershed stress/scarcity agreed with that rating. However, the facilities in the USA were only listed as in a state of high stress by WRF, which agreed with the CDP responses. In addition, GWT listed UK Super Luxury as 'Extremely High' stress, but neither AQE nor WRF agreed. Interestingly, AQE has five facilities in at are higher in stress than either other tool rated (Germany Car and Engine, Japan Car and Truck, and South Korea Car). Also concerning, is CDP had respondents in the Chang Jiang watershed (where China Car and Truck are located) list it as a watershed with a stress risk that impacted operations, but none of the tools rated it above a '2'.

Table 33 Stress States from GWT, AQE, and WRF. CDP Watershed risk present X's (Analytics, 2014b)

		GWT Watershed	Aqueduct	WRF	CDP
Facility	ID #	ARWS (WRI 1995)	BWS (WRI/NASA 2010)	Water Stress (GLOWASIS 2011)	Stress/Scarcity in Watershed
		[m3/person/year]	[ratio]	[ratio]	
USA Car	1	1	1	5	X
USA Truck	2	1	1	5	X
India Car	3	5	5	5	X
India Truck	4	5	5	5	X
Germany Car	5	2	3	2	
Mexico Car	6	4	5	1	X
China Car	7	2	1	1	X
China Truck	8	2	1	1	X
Japan Car	9	1	4	1	
Japan Truck	10	1	4	1	
South Korea Car	11	2	5	2	
Brazil Car	12	1	2	2	
Brazil Truck	13	1	2	2	
UK Super Luxury	14	5	2	2	
Germany Engine	15	2	3	2	
Brazil Transmission	16	1	2	2	

Stress State Legend
1. Low
2. Low to Medium
3. Medium to High
4. High
5. Extremely high

CDP Risk in Watershed
X

The main discrepancies between the tools and CDP are the facilities in China, USA, and Mexico. First, the China Car and China Truck facilities are not shown to be in remarkable stress by any of the tools, yet CDP respondents in the same watershed (CDP information only available at watershed-level) did remark that water stress was impacting operations. The maps of stress from GWT, AQE, and WRF are shown in Figure 93, Figure **94**, and Figure 95, respectively. All three show the China Car and China Truck facility in a location of a low stress state, but AQE and WRF show locations of much higher stress close to the facilities. The GWT does not show any particularly high stress in that particular region. From the examination it can be said that the AQE and WRF tools both agree with the CDP result that there are locations of risk due to stress in the watershed Chang Jiang, but neither tool happened to list the particular location as at risk. However, the GWT lists the entire Change Jiang watershed as being in a state of low stress. Therefore, AQE and WRF have reasonable results for China Car and China Truck, but the GWT result is lacking.

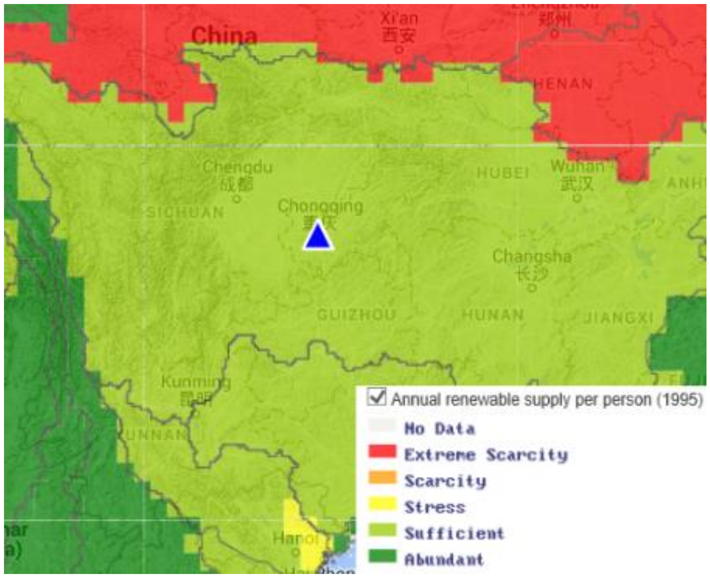


Figure 93 HAC China Car and China Truck shown as blue triangle with GWT Water Stress Mapped

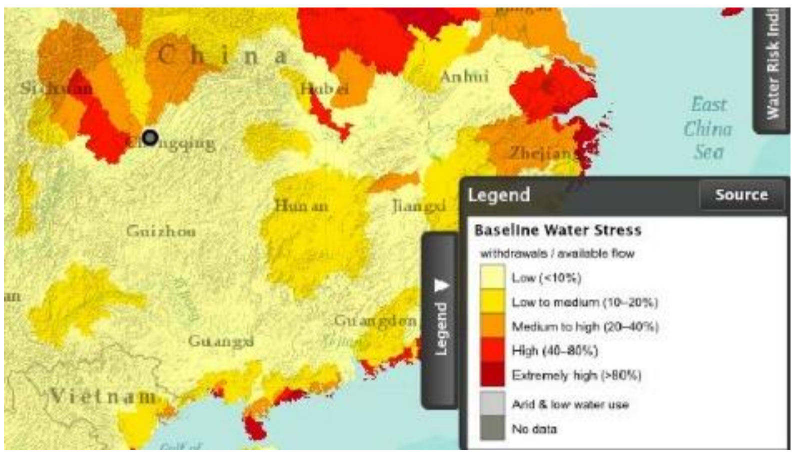


Figure 94 **HAC China Car and China Truck shown as black circle with AQE Water Stress Mapped**

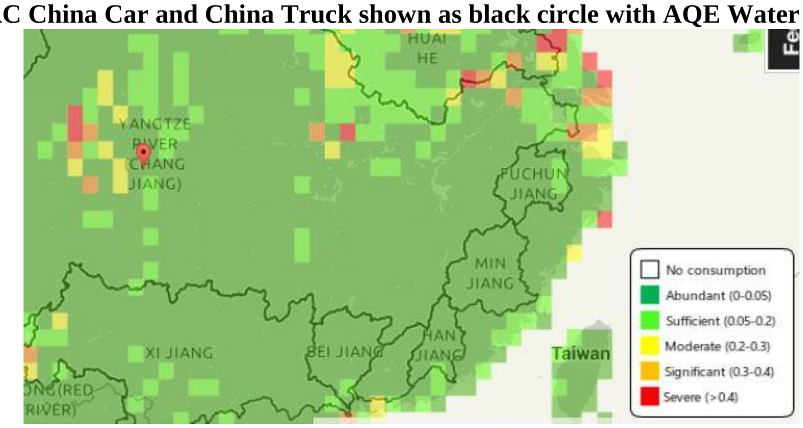


Figure 95 HAC China Car and China Truck shown as red flag with WRF Water Stress Mapped (Note regions of high stress relatively close by)

For the North American facilities (Mexico Car, USA Car, and USA Truck) a similar pattern unfolds. The GWT shows the entire watershed of St. Lawrence as having no water stress, with AQE showing locations of high stress near the facility, and WRF showing the location in an 'Extremely High' stress state. CDP respondents reported there are water stress impacts in the St. Lawrence basin, which agrees with AQE and WRF but not GWT. Mexico Car is in the Rio Grande watershed, which GWT rates as a '4 Scarcity'. AQE and WRF do not follow geographic boundaries, but AQE gave Mexico Car a '5 High Stress' while WRF gave it a '1 Abundant'. WRF also has locations in the watershed that are listed as being in stressed states (3 or above) .CDP respondents reported water stress impacts in the watershed, which would mean that the tools should report stressed locations, and all three do. Although the WRF gives the Mexico Car facility a '1', it does show locations in the watershed as stressed, which does match with CDP and the other tools. A lack of complete overlap between the tools does not mean they are wrong. For the HAC (or any company), a result like this *should* make the company closely monitor the Mexico Car facility because of its' score from two of the tools and the third tool listing highly stressed locations in its proximity. This example shows the limits of comparing company results with the results from the tools. It can be very effective in some cases, such as examining China Car. That example had two tools with reasonable results, and the GWT listing the entire geographic area as having an ample water supply. Since CDP respondents reported water stress as an issue in that area, the GWT result is not representative of the water situation in that region.

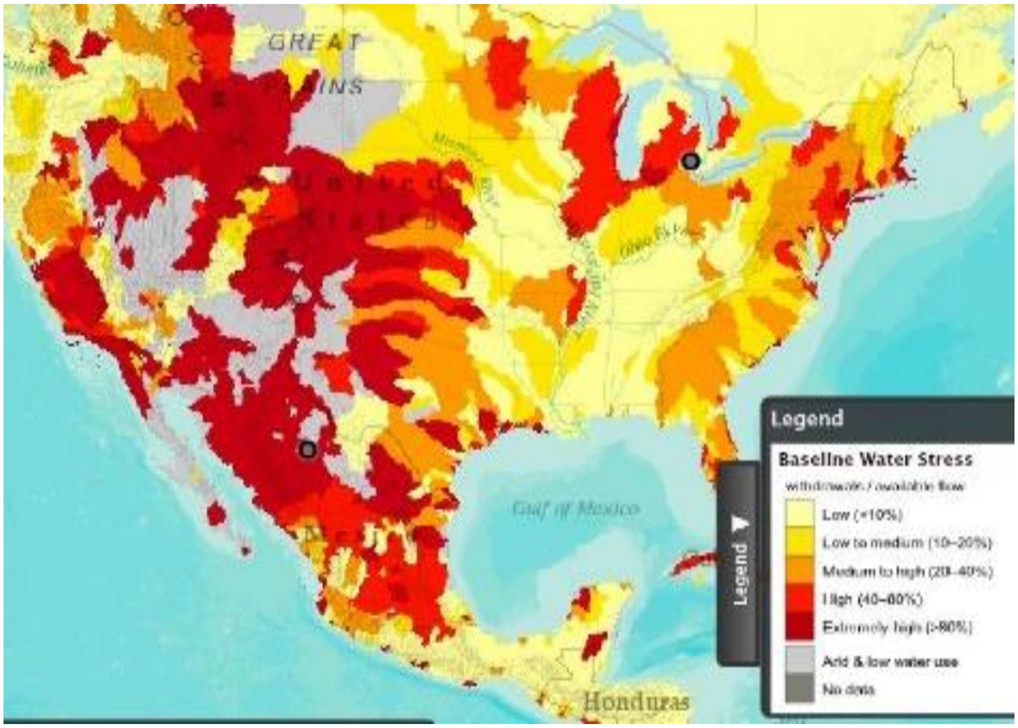


Figure 96 HAC Mexico Car, USA facilities shown as black circles with AQE Water Stress Mapped

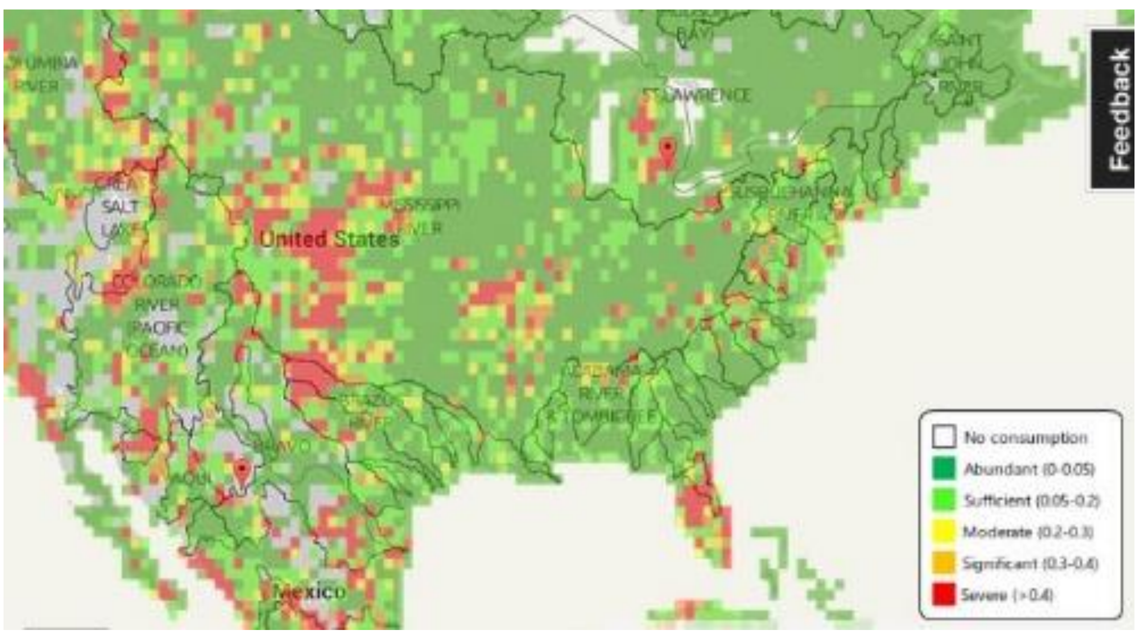


Figure 97 Mexico Car, USA facilities shown as red flags with WRF Water Stress Mapped

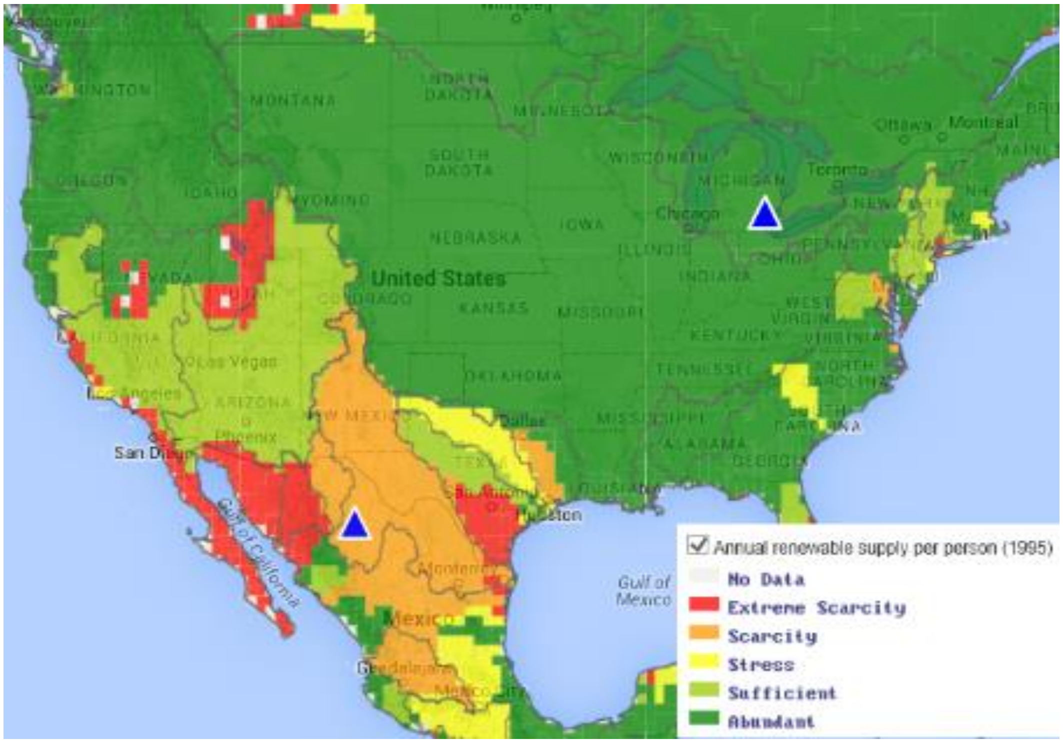


Figure 98 HAC Mexico Car, USA facilities shown as blue triangles with GWT Water Stress Mapped

There are two other significant discrepancies, with GWT listing UK Super Luxury as 'Extremely High' stress state and the German locations being 'Medium to High' from AQE and a 'Low to Medium' from the other tools. These results are close despite being in different states. Fortunately, AQE outputs the raw values of all of its metrics in addition to the state. For the location of HAC Germany Car and Germany Engine the BWS value is 2.5 (WRI, 2014). Essentially, AQE rounded-up the Germany Car and Germany Engine BWS for the assignment of a stress state. Because of the rounding, HAC decision makers can say that the German facilities stress state is not cause for concern based on this in-depth understanding of how the tool arrived at that stress state. For UK Super Luxury, the GWT gave it a '5' state score and the other tools rated it a '2'. All tools mapped stresses are shown in Figure 99, Figure 100, and Figure 101. AQE and the GWT both show a substantial amount of the UK to be in some state of stress (3 or above), but the WRF has only very small areas as being in a stresses state. For the HAC profile, this is the facility that is hardest to come to a consensus conclusion about the results from the CDP. AQE and WRF give it a low score, but GWT gives it an extremely high score. AQE and GWT show high amounts of stress in the area, and WRF does not. A lack of CDP respondents on the issue does not definitively show there *is not* stress in the area.

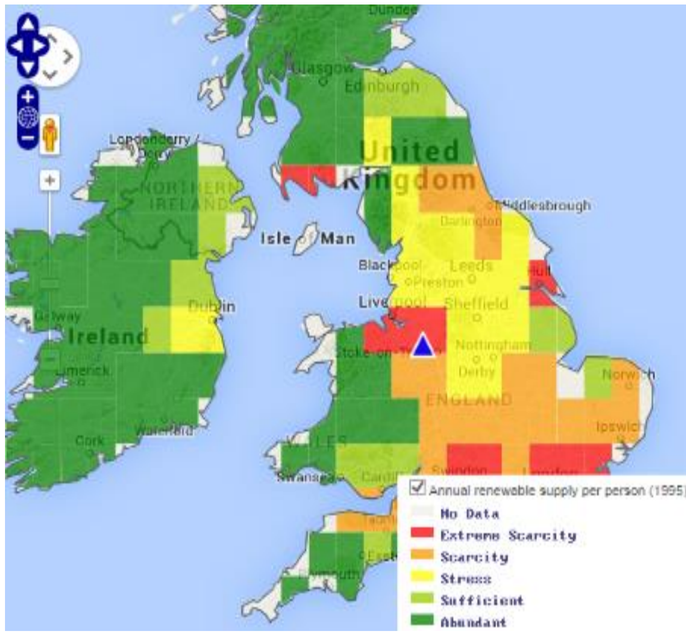


Figure 99 HAC Super Luxury shown as blue triangle with GWT Water Stress Mapped

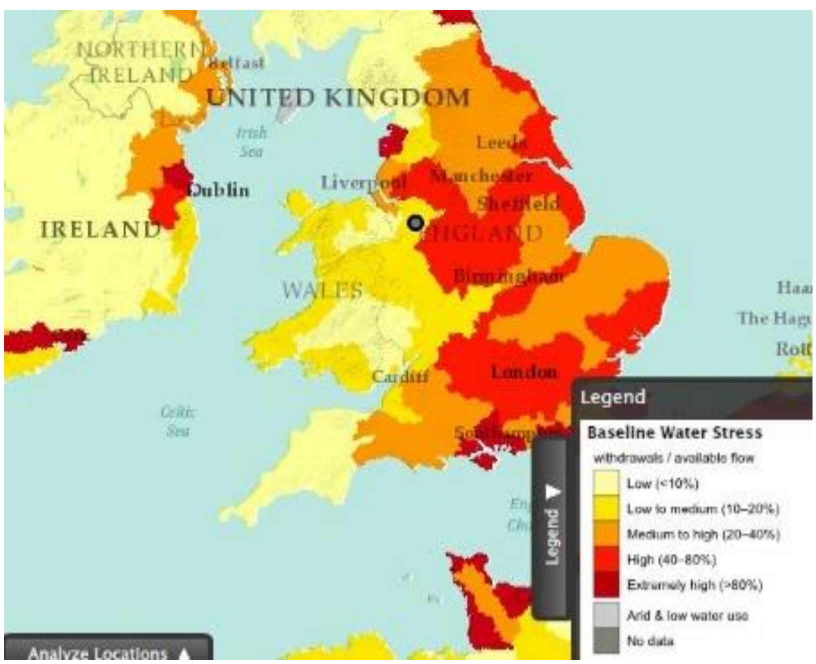


Figure 100 HAC UK Super Luxury facilities shown as black circles with AQE Water Stress Mapped

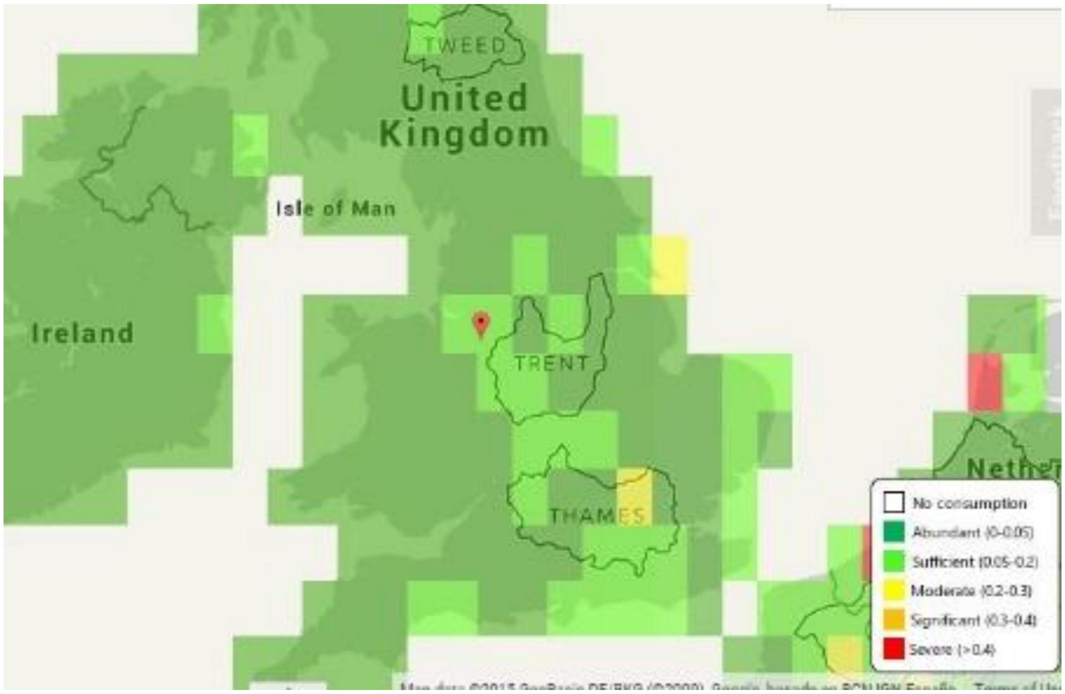


Figure 101 HAC UK Super Luxury shown as red flag with WRF Water Stress Mapped

In order to dive deeper, the tools will be compared in pairs in the subsequent sections. This enables statistical methods that are not available for more than two sets of data.

8.2.3 Analysis of the Scarcity Results from GWT and WRF

The CDP does not distinguish between scarcity and stress explicitly (CDP, 2014). The previous section compared the stress results from the tools, but both the GWT and WRF have scarcity metrics, which are shown with the same CDP watershed stress/scarcity response results in Table 34.

Table 34 Scarcity States from GWT, AQE, and WRF. CDP Watershed risk present X's (Analytics, 2014b)

	WRF	GWT	CDP
Facilities	Annual monthly average scarcity (WFN)	Mean Annual Relative Water Stress Index (2000)	Stress/Scarcity
USA Car	2	< 0.2	X
USA Truck	2	< 0.2	X
India Car	2	< 0.2	X
India Truck	2	< 0.2	X
Germany Car	1	< 0.2	
Mexico Car	2	> 1	X
China Car	1	< 0.2	X
China Truck	1	< 0.2	X
Japan Car	2	< 0.2	
Japan Truck	2	< 0.2	
South Korea Car	1	< 0.2	
Brazil Car	1	< 0.2	
Brazil Truck	1	< 0.2	
UK Super Luxury	2	< 0.2	
Germany Engine	1	< 0.2	
Brazil Transmission	1	< 0.2	

Scarcity State Legend for WRF
1. Low
2. Low to Medium
3. Medium to High
4. High
5. Extremely high

Scarcity Legend for GWT

No Data	Scarce	Stress	Medium	Low
	>1.0	0.4-1.0	0.2-0.4	<0.2

Immediately, and without doing statistical analysis, it is clear that neither scarcity metric from WRF or GWT matched any CDP respondent results, save the Mexico Car scarcity from GWT. Because of this very large discrepancy, the scarcity metrics from GWT and WRF will not be examined further because the GWT only matched 1/7 CDP results and the WRF did not find any of the HAC facilities were in a scarcity state at all for a success rate of 0/7. Both metrics effectively only show scarcity in desert regions, as shown in Figure 102 and Figure 103, with desert regions shown in Figure 104.

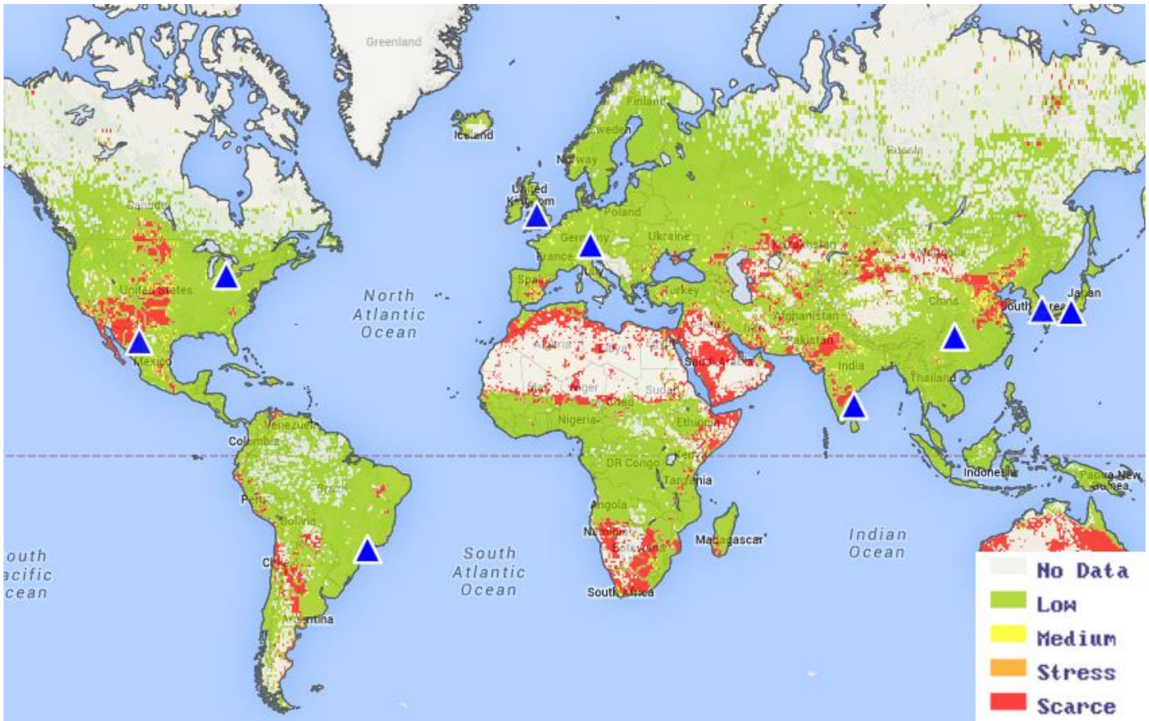


Figure 102 GWT Scarcity with HAC Facilities. Effectively, only desert areas are given stressed states (WBCSD, 2011b)

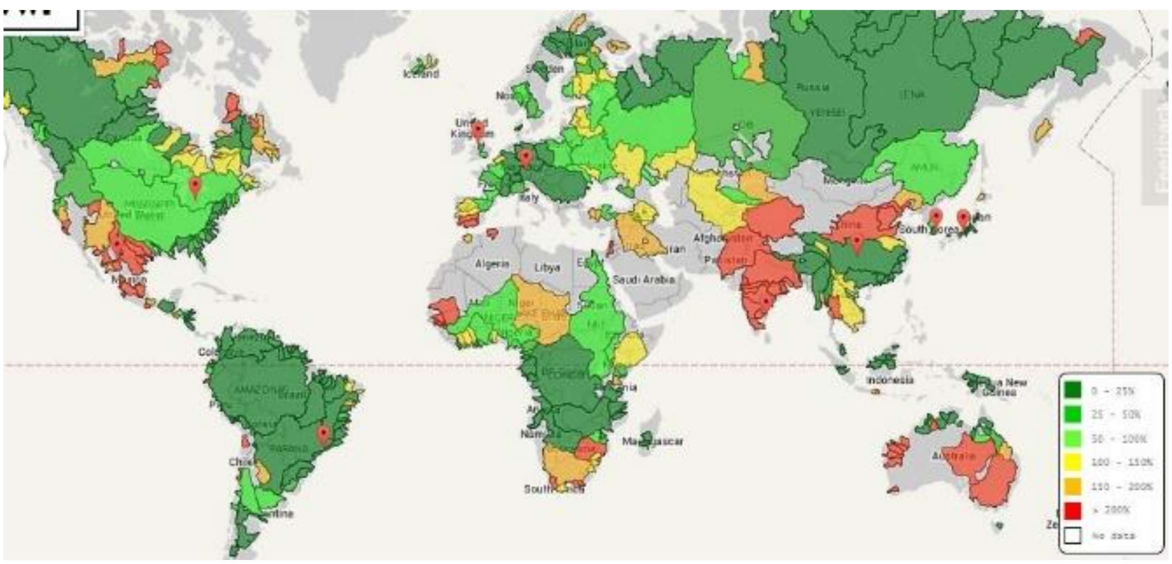


Figure 103 WRF Scarcity with HAC facilities. Effectively, only desert areas are given stressed states except for parts of India (WWF, 2014b)

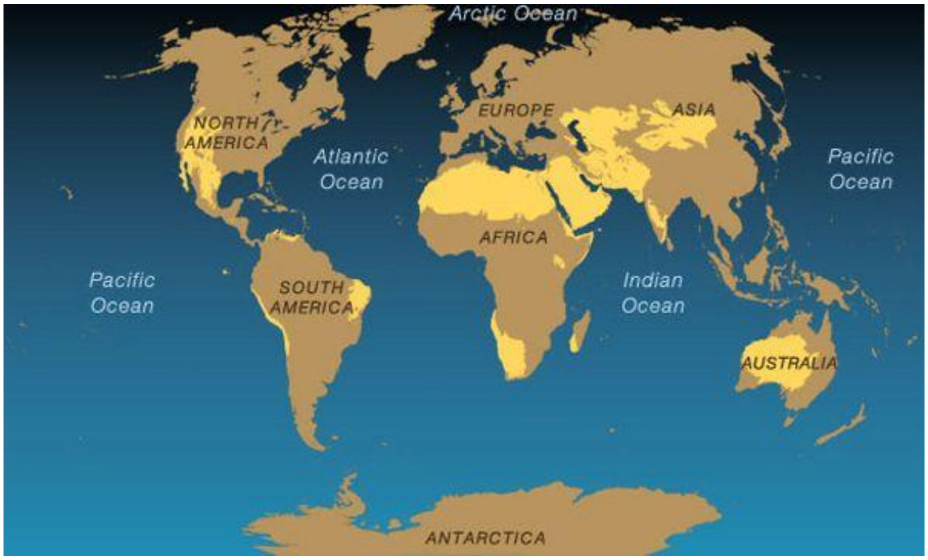


Figure 104 National Geographic Map of World's Deserts (Geographic, 2015)

8.2.4 Statistical Analysis of the Stress Results from GWT and AQE

In order to begin to analyze the relationships further, the tools will be compared in pairs in order to calculate the Spearman Rank, Kendall τ, and Goodman and Kruskal's γ to analyze exactly if state values, rankings, or complete sets agree. Because the ranking will also be examined, Table 35 shows the facilities re-ranked according to the GWT state and the closest matching AQE stress state. Table 36 shows the statistical results.

Table 35 shows the results for Stress State from GWT and AQE for the HAC in normal order of facilities and facilities ranked by the GWT Stress State. This conceptually shows what the ranking statistics are comparing. (Note, the statistical measures are not affected by reordering, it is a visual to for the reader)

Normal Order					Ranked by GWT State			
		GWT Watershed	Aqueduct				GWT Watershed	Aqueduct
Facility	ID #	ARWS (WRI 1995)	BWS (WRI/NASA 2010)		Facility	ID #	ARWS (WRI 1995)	BWS (WRI/NASA 2010)
		[m3/person/year]	[ratio]				[m3/person/year]	[ratio]
USA Car	1	1	1		USA Car	1	1	1
USA Truck	2	1	1		USA Truck	2	1	1
India Car	3	5	5		Brazil Car	12	1	2
India Truck	4	5	5		Brazil Truck	13	1	2
Germany Car	5	2	3		Brazil Transmission	16	1	2
Mexico Car	6	4	5		Japan Truck	10	1	4
China Car	7	2	1		Japan Car	9	1	4
China Truck	8	2	1		China Car	7	2	1
Japan Car	9	1	4		China Truck	8	2	1
Japan Truck	10	1	4		Germany Car	5	2	3
South Korea Car	11	2	5		Germany Engine	15	2	3
Brazil Car	12	1	2		South Korea Car	11	2	5
Brazil Truck	13	1	2		Mexico Car	6	4	5
UK Super Luxury	14	5	2		UK Super Luxury	14	5	2
Germany Engine	15	2	3		India Car	3	5	5
Brazil Transmission	16	1	2		India Truck	4	5	5

Recall Pearson Correlation Coefficient (r) for the two tools stress states is .495 (Table 31 and Table 36). Interestingly, the Spearman Rank ρ (which is similar in principle to Pearson r) is rated as .449. Those results show that the *values* of the stress states agree more than the relative ranking *order*. The Kendall tau correlation is another statistic describing the agreement of the rankings, which only relies on concordant or discordant pairs, which explains the lower agreement score of .337 because it does not reward pairs that are close. Kendall tau also describes a probability and not just the level of agreement. The value of .337 means that there is a 33.7% probability gap between the chance that the pairs are matched in the same order and pairs being in a different order. If the τ value is 1, then there is a complete certainty that the datasets are in matching order. For the GWT and AQE, there is a 33.15% chance that the rankings of a facilities stress states are the same. The γ statistic is preferable for datasets that contain a large number of ties (Conover, 1971) and it is very similar in principle to R and τ. The value of .459 shows moderate agreement, and is a higher value than the R and τ. Finally, the Kendall Coefficient of

Concordance value is .188 is also a 0-1 evaluation of the agreement. However, it was designed to evaluate consistency among raters specifically (Conover, 1971), and a value of .188 shows only a mild agreement among the GWT and AQE stress states.

Table 36 Results of Nonparametric Statistical Analysis for GWT and AQE stress states. Non-Kendall statistics suggest moderate agreement.

Spearman ρ	**0.449**
Kendall Tau τ	**0.337**
Gamma γ	**0.459**
Pearson Correlation Coefficient r	**0.495**
Kendall Coeff. of Concordance	**0.188**

8.2.5 Water Stress/Scarcity GWT AQE Results Discussion

Although there was some disagreement, the tools' results were given relatively good agreement score considering the differences in calculation and datasets. The real issue with these tools is the way stress is defined by each one, with GWT using Falkenmark and AQE using a ratio. The only statistical measure that gives these two tools' results a low score is the Kendall Coefficient of Concordance (W). W is linearly linked to the ρ value for each set of pairs. Because of this, W is greatly affected by the facilities with disagreement from the tools. In order to get a high W rating, both the rankings and values of the states need to correlate very highly. The AQE BWS and GWT ARWS metrics have moderate agreement and moderate ranking agreement for r, ρ, and γ.

8.2.6 Statistical Analysis of the Stress Results from AQE and WRF

The AQE and WRF stress calculations are similar in principle. Both are a water use to water available ratio, and both are measured scientifically. However, as Table 37 shows, the results are quite different. The statistical measures confirm the level of disagreement as shown in Table 38.

Table 37 Stress States from AQE and WRF for the HAC

Facility	ID #	Aqueduct BWS (WRI/NASA 2010) [ratio]	WRF Water Stress (GLOWASIS 2011) [ratio]	Facility	ID #	Aqueduct BWS (WRI/NASA 2010) [ratio]	WRF Water Stress (GLOWASIS 2011) [ratio]
USA Car	1	1	5	China Car	7	1	1
USA Truck	2	1	5	China Truck	8	1	1
India Car	3	5	5	USA Car	1	1	5
India Truck	4	5	5	USA Truck	2	1	5
Germany Car	5	3	2	Brazil Car	12	2	2
Mexico Car	6	5	1	Brazil Truck	13	2	2
China Car	7	1	1	Brazil Transmission	16	2	2
China Truck	8	1	1	UK Super Luxury	14	2	2
Japan Car	9	4	1	Germany Car	5	3	2
Japan Truck	10	4	1	Germany Engine	15	3	2
South Korea Car	11	5	2	Japan Car	9	4	1
Brazil Car	12	2	2	Japan Truck	10	4	1
Brazil Truck	13	2	2	Mexico Car	6	5	1
UK Super Luxury	14	2	2	South Korea Car	11	5	2
Germany Engine	15	3	2	India Car	3	5	5
Brazil Transmission	16	2	2	India Truck	4	5	5

For the WRF, the interesting relation to CDP results is the stress state of the USA Car and USA Truck facilities. All types of CDP responses included stress/scarcity as a factor for operations in the USA, although none were specifically for that watershed or location. Figure 105 and Figure 106 show how the different tools' characteristics come in to play. AQE is at a much higher resolution, and the facility (small black dot) can clearly be seen in a location of 'Low' stress. In the WRF, the resolution is lower, and the USA Car and USA Truck facilities are located at the very bottom of a 'pixel' of information that is in a 'Severe' state. Interestingly, if the facilities locations were a bit further south, the WRF would have listed their state as 'Abundant', which would have been a ‘1’ in the statistical analysis.

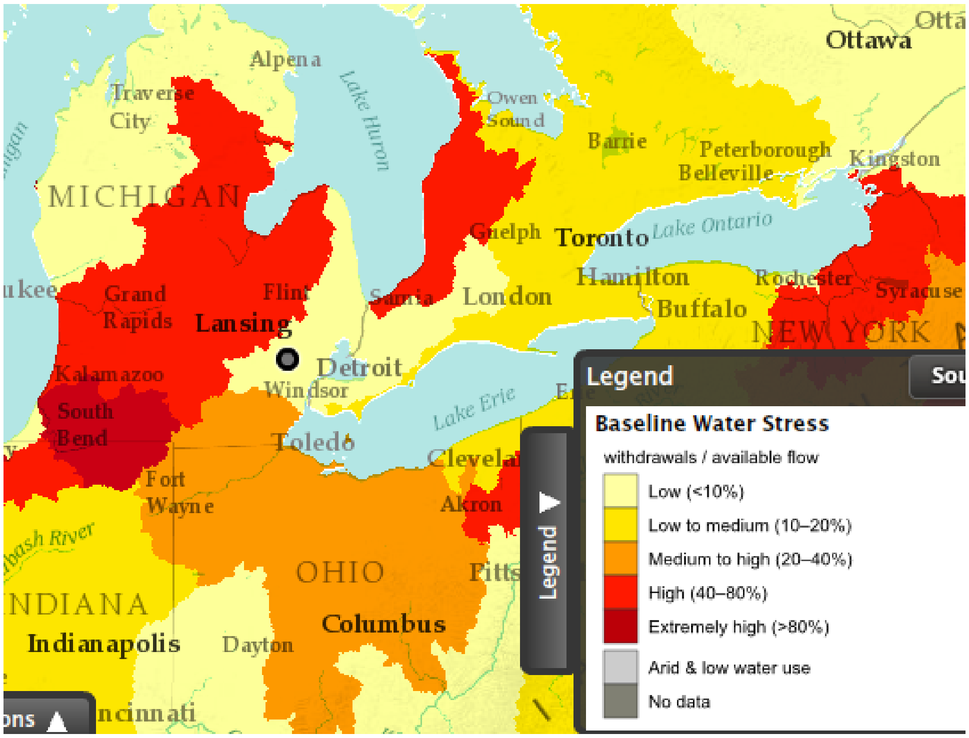


Figure 105 AQE BWS with HAC USA Facilities

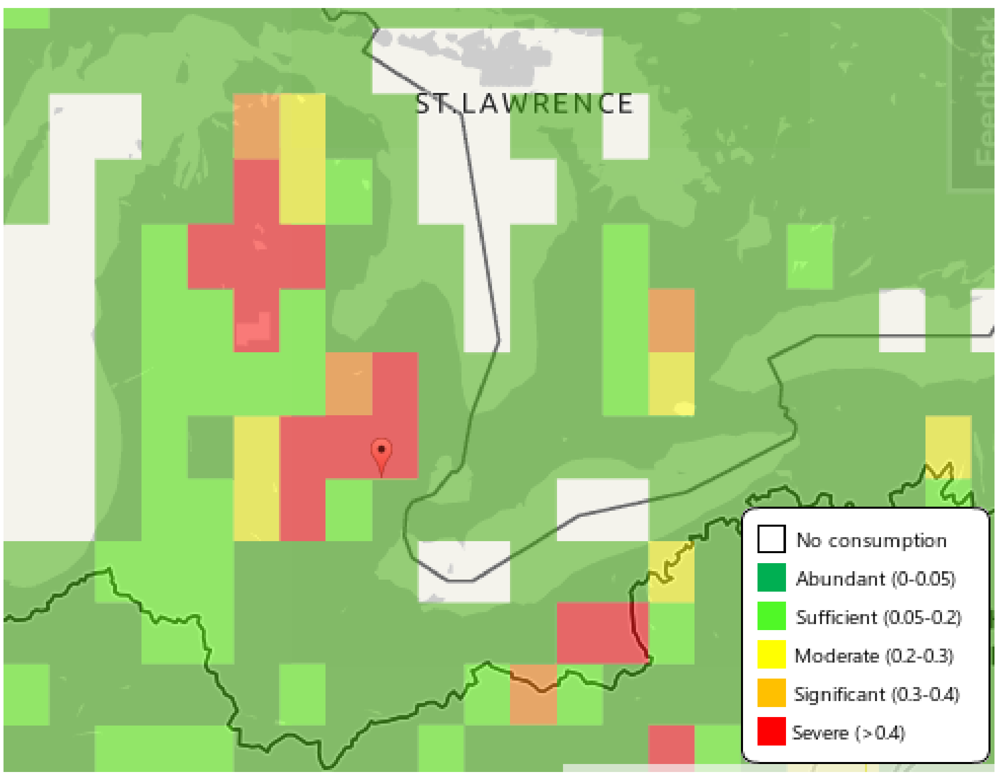


Figure 106 WRF Stress with HAC USA Facilities

Table 38 Results of Nonparametric Statistical Analysis for AQE and WRF stress states. Statistics suggest effectively no agreement.

Spearman ρ	**0.000**
Kendall Tau τ	**-0.020**
Gamma γ	**-0.027**
Pearson Correlation Coefficient r	**0.023**
Kendall Coeff. of Concordance	**0.125**

8.2.7 Discussion of Stress Comparison for AQE and WRF

The statistical results show that the outputs for the stress states of the HAC facilities are very different despite being conceptually similar. The CDP results cannot provide much context for the comparison because the responses are not specific enough for the larger differences in the results. However, the main issue *may* be the resolution with the WRF compared to AQE.

8.2.8 Statistical Analysis of the Stress Results from GWT and WRF

The stress state results from GWT and WRF do not agree particularly well, as shown in Table 37 and statistically measured in Table 38. The statistical results show some interesting relationships. The r value is .274, which shows a mild correlation for the values from the tools. However, all of the metrics that asses the ranking, even in concert with value (such as τ and Concordance) shows very poor relationships between the GWT and WRF stress states.

Facilities in China and Brazil are both listed as areas where CDP responding companies have issues with stress/scarcity. However, both tools listed facilities in those countries as a ‘1’ or ‘2’, corresponding with ‘Low’ or ‘Low to Medium’ stress state.

Table 39 Stress States from GWT and WRF for the HAC

		GWT Watershed	WRF				GWT Watershed	WRF
Facility	ID #	ARWS (WRI 1995)	Water Stress (GLOWASIS 2011)		Facility	ID #	ARWS (WRI 1995)	Water Stress (GLOWASIS 2011)
		[m3/person/year]	[ratio]				[m3/person/year]	[ratio]
USA Car	1	1	5		Japan Car	9	1	1
USA Truck	2	1	5		Japan Truck	10	1	1
India Car	3	5	5		Brazil Car	12	1	2
India Truck	4	5	5		Brazil Truck	13	1	2
Germany Car	5	2	2		Brazil Transmission	16	1	2
Mexico Car	6	4	1		USA Car	1	1	5
China Car	7	2	1		USA Truck	2	1	5
China Truck	8	2	1		China Car	7	2	1
Japan Car	9	1	1		China Truck	8	2	1
Japan Truck	10	1	1		Germany Car	5	2	2
South Korea Car	11	2	2		Germany Engine	15	2	2
Brazil Car	12	1	2		South Korea Car	11	2	2
Brazil Truck	13	1	2		Mexico Car	6	4	1
UK Super Luxury	14	5	2		UK Super Luxury	14	5	2
Germany Engine	15	2	2		India Car	3	5	5
Brazil Transmission	16	1	2		India Truck	4	5	5

Table 40 Results of Nonparametric Statistical Analysis for AQE and WRF stress states. Statistics suggest effectively no agreement.

Spearman ρ	**0.104**
Kendall Tau τ	**0.074**
Gamma γ	**0.119**
Pearson Correlation Coefficient r	**0.274**
Kendall Coeff. of Concordance	**0.007**

8.2.9 Discussion of Results from GWT and WRF Analysis

The two tools results do not agree generally, although there is a fair amount of stress state agreement for some of the facilities (Japan Car, Germany Car and Powertrain, South Korea Car). Overall, the statistical measures shown in Table 40 show the low level of agreement, particularly the γ statistic, which for this thesis has tended to be very optimistic.

8.3 Flooding

Flooding can obviously cause issues for any individual, business, or government. Flooding was rated by CDP respondents as the second most impactful water issue (CDP, 2014). Only the AQE and WRF have a flood water metric to examine (Paul Reig, 2013; WWF, 2014a). The WRF 'Occurrence of Floods' metric is from the Univ. of Colorado database (Brakenridge, 2015; WWF, 2014a) and in the output it is described as "recurrence of large floods… in the period 1985-2005." (WWF, 2015a) The WRI metric is also from the Univ. of Colorado database (Brakenridge, 2015; Paul Reig, 2013). This poses an interesting comparison, because in theory, the tools *should* give exactly the same result if the databases are the same if the databases were the only explanation for the differences seen in previous metrics.

However, despite having the same database for both tools, the results are not the same as shown in Table 41. Interestingly, the facilities are ranked in exactly the same order. Also interestingly, the databases are handled slightly differently for assigning states for flood occurrence. Figure 107 and Figure 108 show the difference. For the WRF, the only way to achieve a '1' is to have had no substantial floods since 1985. For AQE, '0-1' floods would achieve a '1' state. The WRF requires fewer floods for a higher state than AQE, which explains the consistently higher ranking shown in Table 41. The statistical analysis results are shown in Table 42.

Table 41 Flood Occurrence from WRF and AQE for the HAC facilities, both ranked from best to worst.

	WRF	Aqueduct	CDP
	Large floods from 1985-2013	Large floods from 1985-2011	Flood Risk in Watershed
Site	Occurrence of Floods	Flood Occurrence	
Mexico Car	3	3	
South Korea Car	3	3	
USA Car	3	4	X
USA Truck	3	4	X
Germany Car	3	4	X
Germany Engine	3	4	X
India Car	4	4	
India Truck	4	4	
China Car	5	4	X
China Truck	5	4	X
Japan Car	5	4	
Japan Truck	5	4	
Brazil Car	5	4	
Brazil Truck	5	4	
UK Super Luxury	5	4	
Brazil Transmission	5	4	

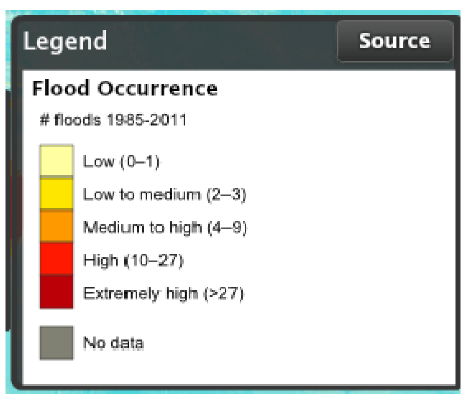


Figure 107 AQE Flood Occurrence Key

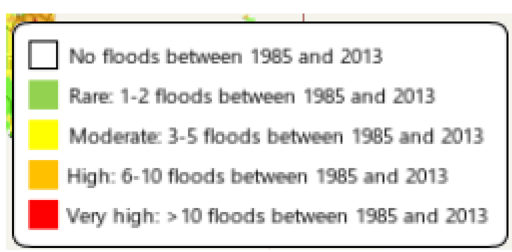


Figure 108 WRF Flood Occurrence Key

Table 42 Results of Nonparametric Statistical Analysis for AQE and WRF Flood Occurrence. Statistics suggest complete agreement on rank order (Gamma) and a great deal of agreement for correlation (Spearman, Pearson) Kendall coefficients had lower values because the actual values (not just the order) of some locations is different between the tools. .

Spearman ρ	**0.452**
Kendall Tau τ	**0.236**
Gamma γ	**1.000**
Pearson Correlation Coefficient r	**0.459**
Kendall Coeff. of Concordance	**0.083**

Table 42 shows a number of interesting properties of the flood results. First, the γ is 1, which means that each set of facilities ranking order was the same. In other words, the order of all the sets was in complete agreement. The ρ and r values show that there are facilities with different state scores, but that there was 'moderate' agreement. Once again, the Kendall coefficients are the most pessimistic, and actually show that the differences in state value keep the sets from complete agreement.

Another difference in the Flood Occurrence is the resolution of the data presented by the tools. Despite having the same database, the WRF gave the information in a much lower resolution. This difference is demonstrated in Figure 109 and Figure 110.

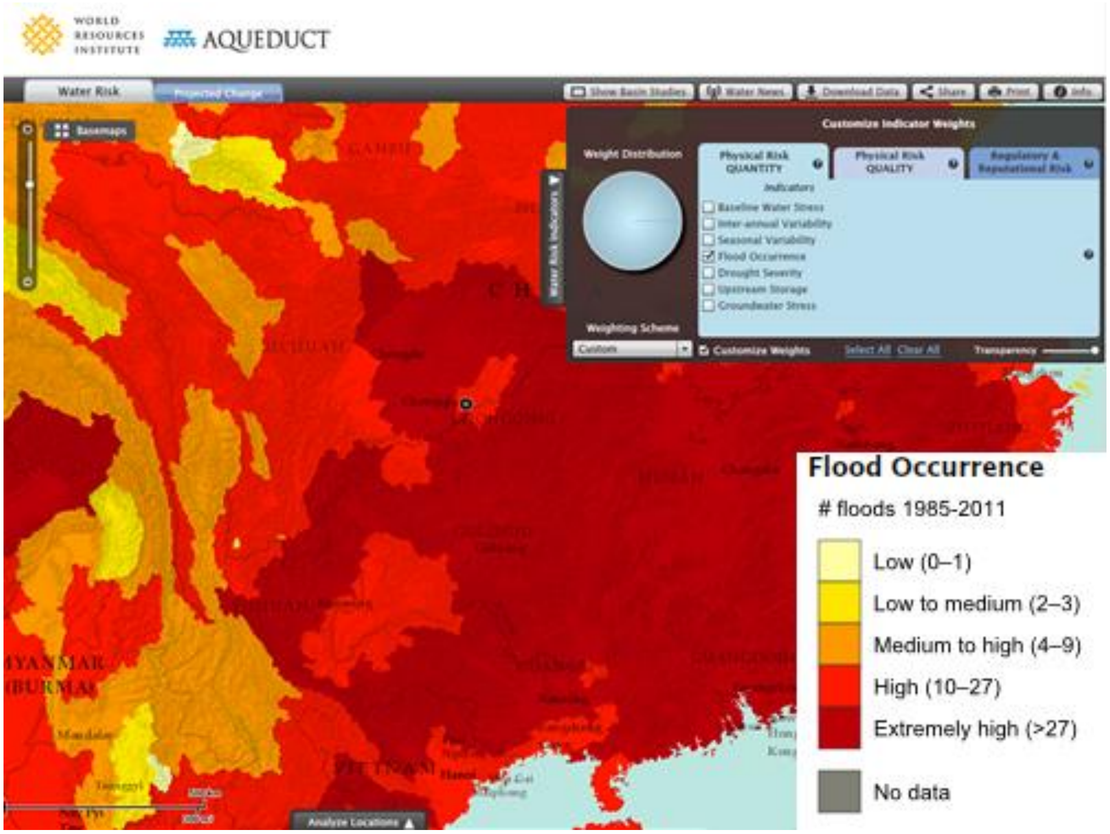


Figure 109 AQE Flood Occurrence in Eastern China. Note the resolution.

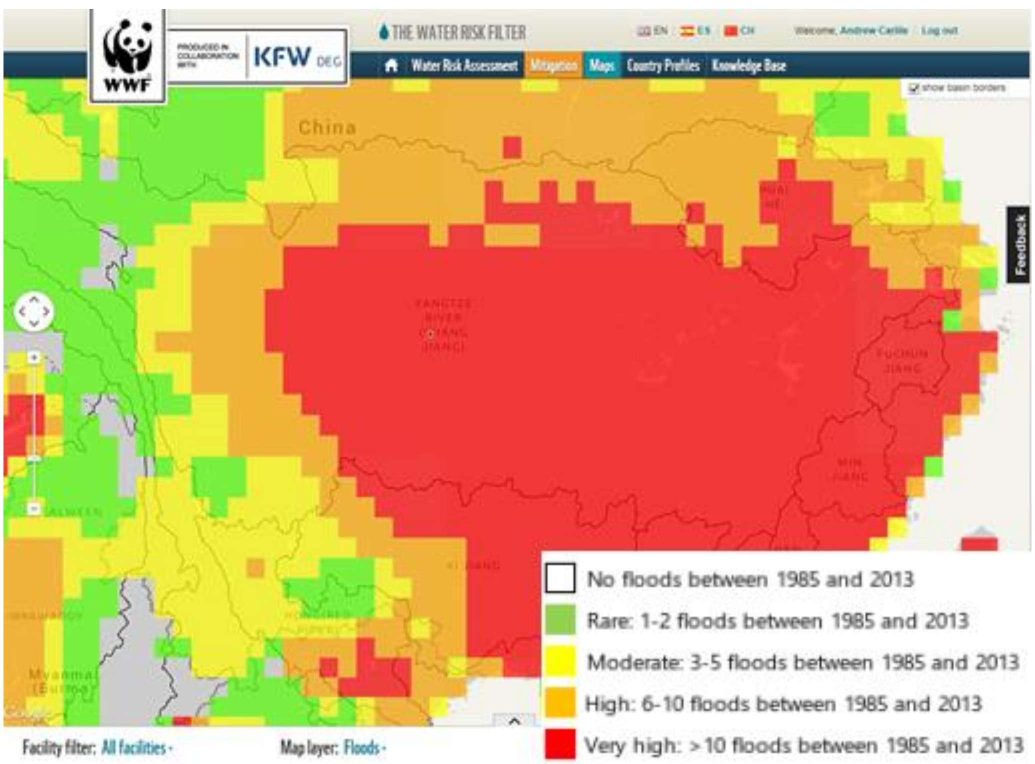


Figure 110 WRF Flood Occurrence in Eastern China. Note the resolution.

The CDP respondents essentially had some flood impacts in all the various countries/watershed except for South Korea (Table 28). Every other region/country was listed at some point for impacts, impact affecting direct operations, or individual respondent results (Analytics, 2014a; CDP, 2014). As both tools list South Korea Car as a lower risk, they both seem to have broad agreement with CDP.

8.3.1 Discussion of Results from AQE and WRF Flood Analysis

The Flood Occurrence metric provided an interesting scenario for AQE and the WRF as they shared a database for this metric. Despite this, the makers of each tool decided to handle the data differently (Paul Reig, 2013; WWF, 2014a). This causes the results of the tool to be different, and according to the Kendall coefficient, substantially so. However, the order of least to highest state was the same. Although the CDP responses do not greatly differentiate any locations or countries, the amount of checking that could be done (essentially having a low score for South Korea Car) was passed by both tools.

8.4 Drought

According to the CDP 2014 Water Report, the third largest impact for respondents was drought (CDP, 2014). However, the CDP respondents also did not have useful results that could be drawn from the data. The country with a large number of responses about drought is Mexico (Analytics, 2014a; CDP, 2014) shown in Table 28. That is not to say that other countries do not have problems with drought, just that Similar to flooding, only the AQE and WRF have a drought water metric to examine (Paul Reig, 2013; WWF, 2014a). However, the AQE drought metric is

“Drought Severity” and the WRF metric is “Estimated Occurrence of Droughts” (Paul Reig, 2013; WWF, 2014a). Since these metrics are measuring different things entirely and their states cannot be compared, there is no statistical comparison to be made.

8.5 Water Quality

According to the CDP respondents, the 4th more impactful water issue is declining water quality (CDP, 2014). Both AQE and WRF have a calculation for the water quality for a facility. The AQE measure is a compilation of the Return Flow Ratio (RFR) and the Upstream Protected Land (Paul Reig, 2013) and shown in Figure 77. WRI defines the Quality as a physical risk, and describes it as: “Physical risks related to quality are defined as the exposure to changes in water quality that may impact a company’s direct operations, supply chains, and/or logistics.” (Paul Reig, 2013) For the comparison from AQE with WRF and CDP, the aggregated “Physical Risk: Quality” calculation will be used. From the WRF, an aggregated quality metric is available as well. The WRF “Physical Risk Pollution (Quality)” metric is a combination of “General situation of water pollution” and 9 other pollution measures (WWF, 2014a). The CDP respondents generally reported issues with water quality in Mexico for watershed level reporting (Analytics, 2014b). From the Data Visualizer, countries with reported quality issues included Brazil and the UK (Water, 2015). Interestingly, for all of the facilities that had data from both tools, all of the facilities were listed as at least ‘Medium to High’. The two tools results are shown in Table 43.

Unfortunately, AQE has no data for the quality metric for South Korea, so for the statistical analysis, the facility will have to be left out. However, with that omission, there is a good deal of agreement between the tools. The statistics are shown in Table 43.

Table 43 Results of Nonparametric Statistical Analysis for AQE and WRF Water Quality. Statistics suggest agreement for ranking of order and mild agreement for assigned values of Water Quality.

Spearman ρ	**0.406**
Kendall Tau τ	**0.210**
Gamma γ	**0.529**
Pearson Correlation Coefficient r	**0.508**
Kendall Coeff. of Concordance	**0.363**

Table 44 AQE and WRF Quality States with CDP Survey Results from Country Level Reports and Watershed Level Reports (Analytics, 2014b; Water, 2015)

			CDP	
	AQE	WRF	Country	Watershed
Facility	Overall Physical Risk QUALITY	Physical - Pollution/ quality	Quality	Quality
USA Car	4. High risk (3-4)	4		
USA Truck	4. High risk (3-4)	4		
India Car	5. Extremely high risk (4-5)	5		
India Truck	5. Extremely high risk (4-5)	5		
Germany Car	3. Medium to high risk (2-3)	4		
Mexico Car	4. High risk (3-4)	3		X
China Car	3. Medium to high risk (2-3)	4		
China Truck	3. Medium to high risk (2-3)	4		
Japan Car	4. High risk (3-4)	4		
Japan Truck	4. High risk (3-4)	4		
South Korea Car	No data	4		
Brazil Car	3. Medium to high risk (2-3)	4	X	
Brazil Truck	3. Medium to high risk (2-3)	4	X	
UK Luxury Car	3. Medium to high risk (2-3)	4	X	
Germany Engine	3. Medium to high risk (2-3)	4		
Brazil Transmission	3. Medium to high risk (2-3)	4	X	

8.5.1 Discussion of Results from AQE and WRF Quality Analysis

The statistics show 'Moderate' agreement for both the rankings and values given to the facilities by the tools. Interestingly, the Kendall Coefficient of Concordance is higher for these results than any other statistic, but the Kendall Tau is relatively low considering the relatively high scores for the other statistics (ρ, γ, and r). The reason for that is the τ does not take into account the values, only if they match or not. The Kendall Coefficient of Concordance does take this into account, which results in a higher value for this set of data. It makes sense that γ is particularly high because it handles ties better than the other statistics, and in these sets, there are 6 ties. It can be concluded from the statistics that the quality metrics from AQE and WRF have a 'moderate' relationship. The CDP results confirm the validity of the results for Brazil, Mexico, and UK, but a lack of reporting for the other locations/countries does not mean those results are not the correct state of water quality in those locations. Similar to flooding, both tools gave results that had moderate agreement, and CDP respondents confirm some of the results with no apparent discrepancies.

8.6 Regulatory and Reputational

The final risk to be statistically analyzed and compared to CDP responses is the Regulatory and Reputational Risk. AQE bases its' Regulatory and Reputational Risk on Media Coverage (by country), Access to Water, and Threatened Amphibians (Paul Reig, 2013). WRF has separate metrics for Regulatory Risk and Reputational Risk (WWF, 2014a). In order to compare the two tools, the Regulatory Risk and Reputational Risk are combined based on the defaults weights for industrial companies given by WRF (WWF, 2014a). For Total Basin Risk, the Regulatory Risk is 25% and the Reputation Risk is 5% (WWF, 2015b), so for this comparison the ratio will be held, with 83.3% weight for Regulatory and 16.6% for Reputational. The results from the tools are shown in Table 45.

Table 45 AQE and WRF Results for Regulatory and Reputation Risk for the HAC Facilities

	AQE	WRF (Basin)	
Facility	Overall Regulatory & Reputational Risk	Regulatory risk	Reputation risk
USA Car	1. Low risk (0-1)	2.6	3.5
USA Truck	1. Low risk (0-1)	2.6	3.5
India Car	3. Medium to high risk (2-3)	3.6	5
India Truck	3. Medium to high risk (2-3)	3.6	5
Germany Car	1. Low risk (0-1)	1	3.5
Mexico Car	2. Low to medium risk (1-2)	3.8	3
China Car	3. Medium to high risk (2-3)	3.6	3.9
China Truck	3. Medium to high risk (2-3)	3.6	3.9
Japan Car	1. Low risk (0-1)	2.6	3.1
Japan Truck	1. Low risk (0-1)	2.6	3.1
South Korea Car	1. Low risk (0-1)	3.9	2.6
Brazil Car	2. Low to medium risk (1-2)	3	5
Brazil Truck	2. Low to medium risk (1-2)	3	5
UK Luxury Car	2. Low to medium risk (1-2)	2.3	3.3
Germany Engine	1. Low risk (0-1)	1	3.5
Brazil Transmission	2. Low to medium risk (1-2)	3	5

Table 46 AQE and WRF Results for Regulatory and Reputation Risk for the HAC Facilities with WRF results weighed to give one overall regulatory and reputational state (Note: raw values rounded to nearest integer for state score, method consistent for all tools)

State Results for Comparison				
	AQE	WRF		
Facility	Overall Regulatory & Reputational Risk	Overall Regulatory & Reputational		
Germany Car	1	1		
Germany Engine	1	1		
USA Car	1	3		
USA Truck	1	3		1. Low
Japan Car	1	3		2. Low to Medium
Japan Truck	1	3		3. Medium to High
South Korea Car	1	4		4. High
UK Luxury Car	2	2		5. Extremely high
Brazil Car	2	3		
Brazil Truck	2	3		
Brazil Transmission	2	3		
Mexico Car	2	4		
India Car	3	4		
India Truck	3	4		
China Car	3	4		
China Truck	3	4		

Table 47 HAC Facilities Regulatory and Reputational Risk with CDP results for impacts based on regulatory or reputational risks (Water, 2015)

State Results for Comparison			
	AQE	WRF	CDP Country
Facility	Overall Regulatory & Reputational Risk	Overall Regulatory & Reputational	Regulatory and Reputational
Germany Car	1	1	
Germany Engine	1	1	
USA Car	1	3	X
USA Truck	1	3	X
Japan Car	1	3	X
Japan Truck	1	3	X
South Korea Car	1	4	
UK Luxury Car	2	2	
Brazil Car	2	3	X
Brazil Truck	2	3	X
Brazil Transmission	2	3	X
Mexico Car	2	4	X
India Car	3	4	X
India Truck	3	4	X
China Car	3	4	X
China Truck	3	4	X

1. Low
2. Low to Medium
3. Medium to High
4. High
5. Extremely high

CDP Risk in Country
X

The CDP respondent results do show trends that can be used for comparison with the results from the tools. Effectively, all of the countries in which the HAC operates except for Germany, South Korea, and UK have some respondents reporting reputational and regulatory risks (Water, 2015). The WRF results match very well with the CDP results (Table 47), except for giving South Korea Car a high score. However, this does not mean that score is invalid, because there could be companies experiencing that issue and not reporting to CDP. AQE however, only scores facilities in China and India as at a risk state of concern (3 or above) of the HAC facilities. This is concerning because CDP respondents reported issues in countries were AQE reports as being at low risk for reputational and regulatory risks.

The two tools correlation statistics suggest agreement for all of the statistics, with both γ and W measuring as ‘Strong’ correlations between the tools. This is primarily because the ranking of the facilities by the tools agrees with the exception of UK Luxury Car and South Korea Car.

However, in the case of UK Luxury Car, the state was the same, AQE just ranked it as a higher stress relative to the other facilities than WRF did. The only disparities in state score were for facilities in Japan, South Korea, and the USA. However, the ranking order of the facilities still matched generally.

Table 48 Results of Nonparametric Statistical Analysis for AQE and WRF Regulatory and Reputational Risk. Statistics suggest moderate to strong agreement.

Spearman ρ	**0.609**
Kendall Tau τ	**0.465**
Gamma γ	**0.742**
Pearson Correlation Coefficient r	**0.576**
Kendall Coeff. of Concordance (W)	**0.813**

8.6.1 Discussion of Results from AQE and WRF Regulatory and Reputational Risk

AQE consistently had lower risk states for all facilities, and a global map of the Regulatory and Reputational Risk shows the seemingly optimistic picture from AQE in Figure 111 (WRI, 2014). The problem is that CDP respondents have reported Regulatory and Reputational Risk in countries where AQE scores a low risk.

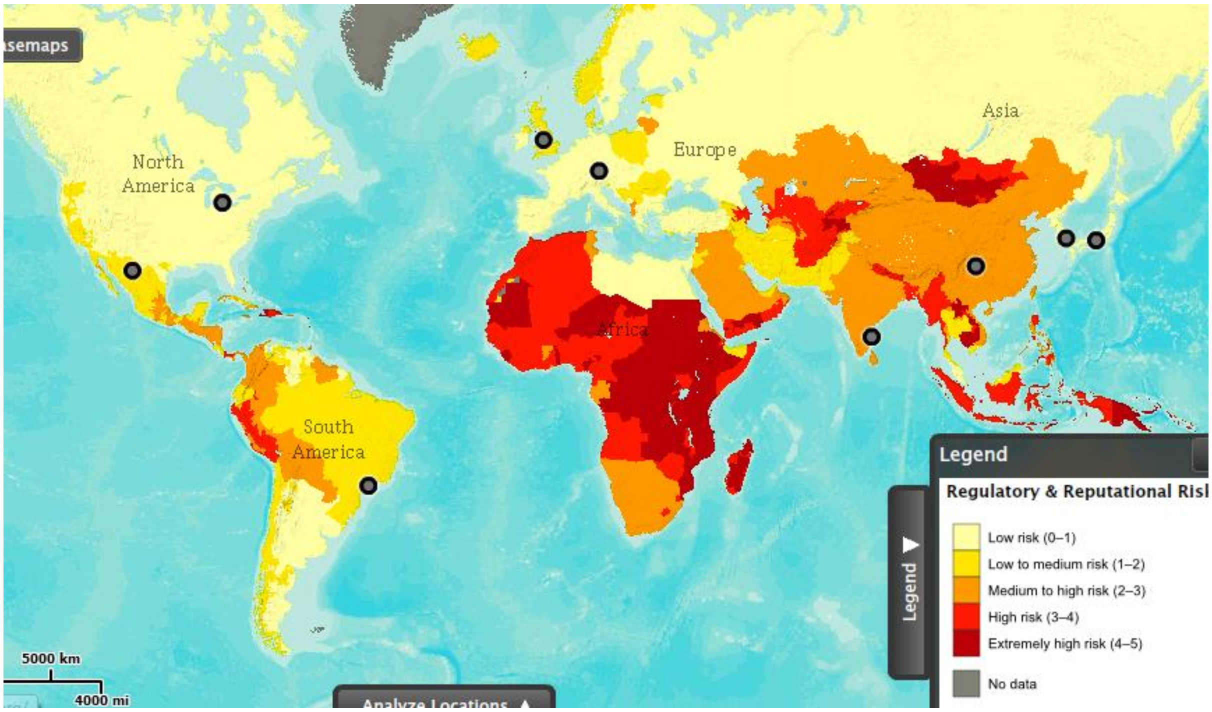


Figure 111 AQE Regulatory and Reputational Risk with HAC facilities

Despite this, the ranking order and values of risk states between the tools had broad agreement with each other, as seen in Table 48. The results from WRF did match CDP respondent reported risks much better than AQE however.

8.7 Key Metric and CDP Results Discussion

The CDP 2014 Global Water Report specified the top five water risks as water stress/scarcity, flooding, drought, quality, and regulatory & reputational risks (CDP, 2014).The three tools each had stress metrics for comparison, but for the other four factors, only AQE and the WRF had available results. An additional problem is the lack of standardization of metrics among the tools, and in water analysis more broadly (Paul Reig, 2013; WBCSD, 2011b; WWF, 2014a). Despite this, all of the tools give their results for these metrics in states ranked 1-5. This enables statistical comparison of the results as all the tools had '3' and above as 'stressed' or 'at risk' for the label of the state. With these results, a comparison with CDP respondents stress and risks was made. CDP results were collected from the Data Visualizer (Water, 2015) and the Analytic results (Analytics, 2014b) directly from respondents. These results can positively identify watersheds or countries that are experiencing a given water issue or risk. If a CDP report listed the particular water issue in a watershed or country, then it would be expected that the tools would give a '3' or above or have risks present in the given country or watershed.

The big differentiating factors were that the resolutions of AQE and WRF did not match, and the GWT gives results for watersheds and not particular GPS coordinates (Paul Reig, 2013; WBCSD, 2011b; WWF, 2014a). The way each metric was calculated was also different. However, the stress state comparisons showed that each tools gave results that broadly agreed with the CDP responses. Table 49 shows that for the GWT results, AQE and GWT had moderate agreement, even is the agreement with WRF was not as strong.

Table 49 Gamma and Pearson Coefficient for HAC Stress Results for GWT, AQE, and WRF. Effectively: rank agreement (γ), state agreement (r)

	GWT Stress	
	γ	r
AQE Stress	**0.459**	**0.495**
WRF Stress	**0.119**	**0.274**

For the other water issues, the GWT did not provide any results. Table 50 shows the general agreement for the additional metrics. Interestingly, the stress metrics from the tools have no correlation (effectively 0 for γ and r). Other than that relationship, the tools generally agreed with each other, with a minimum of 'moderate' agreement up to 'strong'. Some of the results did correlate very well with the CDP respondents, such as Flood Occurrence. For the drought metrics, no analysis was done because the metrics were entirely different, with WRF doing Drought Occurrence (WWF, 2014a) and AQE having Drought Severity (Paul Reig, 2013). For Quality, there was 'moderate' agreement between the tools, and the CDP respondents reported issues in the same localities that the tools reported. Unlike Quality, the Regulatory & Reputational results for the tools had an issue. Although the WRF broadly agreed with CDP, the AQE results were seemingly optimistic given the results.

Table 50 Gamma and Pearson Coefficient for HAC metric results for AQE and WRF. Effectively: rank agreement (γ), state agreement (r)

		AQE	
		γ	r
WRF	Stress	-0.027	0.023
	Flood Occurrence	1.000	0.459
	Drought	-	-
	Quality	0.529	0.508
	Reg. & Rep.	0.742	0.576

The results from the tool for physical (i.e. Scarcity or Stress Metrics) and their projections are shown in Table 51 and Table 52.

Table 51 shows the results from the three tools for stress and scarcity metrics

Current State

	GWT			WRF				AQE		
	Annual Renewable Water Supply per Person (1995) m3/person/year	Mean Annual Relative Water Stress Index (2000) ratio	Total Renewable per person (actual) (TRWR/person) (2008) m3/person/year	Final score Basin related risk score	Physical - Scarcity/ quantity score	Annual monthly average scarcity (WFN) ratio	*Annual monthly average scarcity (GLWOASIS)* ratio	Overall Water Risk score	Overall Physical Risk QUANTITY score	Baseline Water Stress ratio
USA Car	> 4,000	< 0.2	9,789.00	3	2.7	2	5	1.2	1.2	0
USA Truck	> 4,000	< 0.2	9,789.00	3	2.7	2	5	1.2	1.2	0
India Car	< 500	< 0.2	1,591.00	3.4	1.6	2	5	3.6	3.6	5
India Truck	< 500	< 0.2	1,591.00	3.4	1.6	2	5	3.6	3.6	5
Germany Car	1,700 - 4,000	< 0.2	1,872.00	2.2	1.4	1	2	2.1	2.6	2.5
Mexico Car	500 - 1,000	> 1	4,212.00	3.2	2.9	2	1	2.9	2.9	4
China Car	1,700 - 4,000	< 0.2	2,104.00	3.1	1.7	1	1	2	1.7	0
China Truck	1,700 - 4,000	< 0.2	2,104.00	3.1	1.7	1	1	2	1.7	0
Japan Car	> 4,000	< 0.2	3,378.00	2.9	2.2	2	1	2.8	3.4	3.6
Japan Truck	> 4,000	< 0.2	3,378.00	2.9	2.2	2	1	2.8	3.4	3.6
South Korea Car	1,700 - 4,000	< 0.2	1,447.00	2.7	1	1	2	3.2	3.7	5
Brazil Car	> 4,000	< 0.2	42,886.00	3.1	1.9	1	2	1.7	1.7	1.5
Brazil Truck	> 4,000	< 0.2	42,886.00	3.1	1.9	1	2	1.7	1.7	1.5
UK Super Luxury	< 500	< 0.2	2,392.00	3	2.9	2	2	1.9	1.9	1.8
Germany Engine	1,700 - 4,000	< 0.2	1,872.00	2.2	1.4	1	2	2.1	2.6	2.5
Brazil Transmission	> 4,000	< 0.2	42,886.00	3.1	1.9	1	2	1.7	1.7	1.5

Table 52 shows the projections from each tool. The GWT projections are for Falkenmark stress with no climate change or economic projections included. The WRF metric is a countries' ability to respond to climate change, and the AQE metric is the change in water stress

Projections

	GWT		WRF	AQE
	Annual Renewable Water Supply per Person (Projections for 2025) m3/person/year	Total Renewable per person (actual) (TRWR/person) (2050) m3/person/year	Impact climate change (2050 A2) score	Projected Change in Water Stress Scenarios (2050 A2)
USA Car	> 4,000	7,553.25	1	Near Normal Conditions
USA Truck	> 4,000	7,553.25	1	Near Normal Conditions
India Car	< 500	1,164.95	2	Moderately More Stressed
India Truck	< 500	1,164.95	2	Moderately More Stressed
Germany Car	1,700 - 4,000	2,184.27	2	Near Normal Conditions
Mexico Car	< 500	3,545.18	2	Near Normal Conditions
China Car	1,700 - 4,000	1,984.21	4	Moderately More Stressed
China Truck	1,700 - 4,000	1,984.21	4	Moderately More Stressed
Japan Car	> 4,000	4,229.83	1	Near Normal Conditions
Japan Truck	> 4,000	4,229.83	1	Near Normal Conditions
South Korea Car	1,700 - 4,000	1,581.32	3	Near Normal Conditions
Brazil Car	> 4,000	37,677.56	2	Severely More Stressed
Brazil Truck	> 4,000	37,677.56	2	Severely More Stressed
UK Super Luxury	500 - 1,000	2,025.21	2	Near Normal Conditions
Germany Engine	1,700 - 4,000	2,184.27	2	Near Normal Conditions
Brazil Transmission	> 4,000	37,677.56	2	Severely More Stressed

In general, the tools matched well with the locations where CDP respondents reported issues. With the exception of stress and scarcity, the tools had approximately ‘moderate’ agreement, despite having different resolutions and datasets. Of the tools, the WRF did seems to have the most consistent results with CDP and had the largest set of metrics. That being said, AQE did have advantages such as higher resolution, mapping of custom weights, and projections not available in the other tools. The GWT does have a large collection of metrics, but only a few related to water issues that impact the operations of a company. In general, the results do need to be examined in depth to understand exactly what the results mean.

CHAPTER 9 INDIRECT WATER USE OF AUTOMOTIVE MANUFACTURING

9.1 Indirect Water Use and Energy Generation Use

For automotive manufacturing in general, the water use is an important resource because it impacts cost, brand image, and the relationship with the local actors near facilities (CDP, 2014). According to the WRF, the water use also relates to the risk exposure of the company's facilities (WWF, 2014a). Having a complete understanding of the indirect water use is important, because even if the water isn't directly withdrawn for a facility, that water is removed from the source and is unavailable for other purposes, which can increase the stress in a location (Joost Schornagela, 2012). This chapter examines two indirect water users that can have a significant water impact: workers and electricity generation.

9.2 Energy Generation Indirect Water Use

The manufacturing of vehicles requires the use of electricity, and that electricity usage also contributes to indirect water use (Semmens et al., 2014). Automotive manufacturing companies track their energy use and disclose it in their corporate sustainability reports (CSR). With that information, it is possible to find an average energy use per vehicle number that can be used with the HAC profile to examine the energy use for the facilities. With that information, the electricity generation profiles from the respective countries occupied by HAC facilities can be used to estimate the indirect water consumption and withdrawal.

9.2.1 Background for Calculations of Electricity

9.2.1.1 Energy Use per Production from Automaker CSR's

Various automakers publically report their energy intensity per vehicle values in their CSR's. Table 53 is a collection of these values from six different major automakers. The average value of 2.29 MWh/vehicle will be used in conjunction with the HAC profile for the indirect usage calculation of total electricity.

Table 53 Energy Intensities from Various Automakers CSR's

Automaker	Most Recent Energy Usage per Vehicle Globally (MWh/vehicle)
GM (GM, 2014a)	**2.22**
Volkswagen (Dooley et al., 2013; VW, 2014d)	**2.21**
Ford (Ford, 2014a)	**2.44**
Nissan/Renault (Nissan-Renault, 2014)	**2.19**
Peugeot SA (Peugeot, 2014)	**2.30**
BMW (BMW, 2014b)	**2.36**
Average	**2.29**

Table 54 Collection of Water Consumption and Withdrawal Values for Different Electricity Sources

Electricity Source	Water Consumption (m^3/MWH) (Dooley et al., 2013)	Water Withdrawal (m^3/MWh) (Dooley et al., 2013)
Coal	1.775	80.9
Natural Gas	0.565	25.23
Nuclear	1.78	98.59
Hydroelectric	17	0
Solar	0.02	0.02

9.2.1.2 Indirect Water Withdrawal and Consumption based on Electricity Generation

Many different researchers and organizations have calculated values of water withdrawal and consumption by energy generation type for the use in life cycle assessments. Two papers that aggregate some of these results are by Semmens (Semmens et al., 2014) and Dooley (Dooley et al., 2013). Table 54 is a collection of the information from Dooley used to calculate the indirect water withdrawal and consumption. The final consumption values can be compared to results for per vehicle indirect consumption from Semmens et al, which is shown in Table 55.

Table 55 Results for Indirect Water Consumption by Electricity from (Semmens et al., 2014)

	[m^3/vehicle]
BMW	1.91
Chrysler	3.32
Daimler	3.69
Ford	2.41
GM	1.80
Honda	2.27
Hyundai	2.25
Kia	1.24
Mazda	2.12
Nissan	1.54
Volkswagen	1.77
Average	2.21

9.2.1.3 Electricity Generation by Source in HAC Countries

With the water use information for different sources, the other piece of information needed to calculate the indirect water use by electricity is to find the electricity resource profiles for the countries where the HAC operates. The IEA (IEA, 2012) tracks the electricity resource profiles of a majority of countries worldwide. The IEA statistics were in GWh for each type of resource, so to create a percentage profile, the GWh for each resource was divided by the total GWh for that country, and included in Table 56.

Table 56 Electricity Resource Profile for Selected Countries (IEA, 2012)

	Coal	Natural Gas	Nuclear	Solar (PV)	Wind	Hydro
Brazil	2.6%	8.5%	2.9%	0.0%	0.9%	75.2%
China	75.8%	1.7%	2.0%	0.1%	1.9%	17.5%
Germany	45.6%	12.3%	15.8%	4.2%	8.0%	4.4%
India	71.1%	8.3%	2.9%	0.2%	2.5%	11.2%
Japan	29.3%	38.4%	1.5%	0.7%	0.5%	8.1%
Mexico	11.7%	51.4%	3.0%	0.0%	1.2%	10.8%
South Korea	44.8%	20.9%	28.1%	0.2%	0.2%	1.4%
UK	39.6%	27.5%	19.4%	0.3%	5.4%	2.3%
USA	38.3%	29.5%	18.7%	0.2%	3.3%	7.0%

With the average electricity use for a vehicle, water withdrawal and consumption for different types of electricity generation, and the resource profiles of the countries in which the HAC operates, it is now possible to calculate the indirect water withdrawal and consumption for the HAC.

9.2.2 Calculation of Indirect Water Use by Energy

The HAC profile established a realistic production number for the different facilities with respect to their location. With realistic production information and the average energy intensity use from automakers CSR's (Table 53) it is possible to calculate the electricity usage for each facility in the HAC. With the country based electricity resource profile, the MWh usage by each facility can be broken down by electricity source, which can be multiplied by the water withdrawal or consumption information to find the indirect withdrawal or consumption by each facility. This equation is shown in Equation 12 for Indirect Withdrawal and Equation 13 for Indirect Consumption.

Equation 12 Calculation of Indirect Withdrawal by an HAC Facility's Electricity Use

$$Indirect\ Withdrawal\ [\frac{m^3}{year}]$$
$$= Annual\ Production\ \left[\frac{vehicle}{year}\right] * Elec.Intensity\ \left[\frac{MWh}{vehicle}\right]$$
$$* \sum Resource\ Profile\ [\%] * Water\ Withdrawal\ by\ Resource\ [\frac{m^3}{MWh}]$$

Equation 13 Calculation of Indirect Consumption by an HAC Facility's Electricity Use

$$Indirect\ Consumption\ [\frac{m^3}{year}]$$
$$= Annual\ Production\ \left[\frac{vehicle}{year}\right] * Elec.Intensity\ \left[\frac{MWh}{vehicle}\right]$$
$$* \sum Resource\ Profile\ [\%] * Water\ Consumption\ by\ Resource\ [\frac{m^3}{MWh}]$$

These equations follow the standard practice used to calculate the water consumption and withdrawal from electricity sources (Dooley et al., 2013; Semmens et al., 2014). The novelty of calculating both types of water use is that withdrawal is typically not calculated as an indirect use. Many CSR's from automakers include indirect CO2 emissions, indirect waste, or indirect water consumption, but none documented include indirect water withdrawal due to energy (BMW, 2014b; Fiat-Chrysler, 2014; Ford, 2014a; GM, 2014a; Nissan-Renault, 2014; Peugeot, 2014; VW, 2014d).

9.2.3 Indirect Water Withdrawal and Consumption by HAC

9.2.3.1 Indirect Withdrawal

The indirect withdrawal from electricity for the HAC facilities is substantially higher than the direct withdrawal by the facility. The per vehicle withdrawal numbers are typically from 2 m^3 – 6 m^3 (with UK Super Luxury being 55 m^3). The indirect withdrawal from electricity values are typically approximately 80-140 m^3 per vehicle and the results (including total electricity and total indirect withdrawal) are shown in Table 57.

Table 57 HAC Facilities Indirect Electricity Withdrawal

HAC Profile		Calculations based on IEA Profiles (IEA, 2012) and Resource Withdrawal (Dooley et al., 2013)		
Facility	Production per Year [vehicles]	Total Electricity by Facility [MWh/year]	Total Indirect Withdrawal for Electricity Production [m^3/year]	Total Indirect Withdrawal for Electricity Production [m^3/vehicle]
USA Car	100,000	229,000	13,014,595	130
USA Truck	200,000	458,000	26,029,190	130
India Car	50,000	114,500	7,152,717	143
India Truck	100,000	229,000	14,305,433	143
Germany Car	200,000	458,000	25,440,069	127
Mexico Car	50,000	114,500	2,902,216	58
China Car	50,000	114,500	7,290,045	146
China Truck	100,000	229,000	14,580,090	146
Japan Car	100,000	229,000	7,998,180	80
Japan Truck	200,000	458,000	15,996,361	80
South Korea Car	500,000	1,145,000	79,260,853	159
Brazil Car	50,000	114,500	809,742	16
Brazil Truck	100,000	229,000	1,619,484	16
UK Luxury Car	2,000	4,580	265,998	133
Germany Engine	1,000,000	2,290,000	127,200,347	127
Brazil Transmission	1,000,000	2,290,000	16,194,842	16

In order to compare the ratio of indirect water withdrawal from electricity to the direct withdrawal from the facilities themselves, a factor called Indirect Electricity Withdrawal Factor (IEWF) is created to show this ratio. The IEWF is simply the Total Indirect Withdrawal per Vehicle divided by the Direct Withdrawal per Vehicle.

Table 58 HAC Facilities Indirect Electricity Withdrawal Factor Results

Facility	Total Indirect Withdrawal per Vehicle [m^3/vehicle]	Direct Withdrawal per Vehicle [m3/vehicle]	Indirect Electricity Withdrawal Factor
			IEWF
USA Car	130	4	32.5
USA Truck	130	4	32.5
India Car	143	4	35.8
India Truck	143	4	35.8
Germany Car	127	2.5	50.9
Mexico Car	58	4	14.5
China Car	146	4	36.5
China Truck	146	4	36.5
Japan Car	80	4	20.0
Japan Truck	80	4	20.0
South Korea Car	159	4	39.6
Brazil Car	16	4	4.0
Brazil Truck	16	4	4.0
UK Luxury Car	133	55	2.4
Germany Engine	127	0.2	636.0
Brazil Transmission	16	0.2	81.0

This factor is roughly analogous to the Employee Water Factor in that is not a measure of how efficient a facility uses water, but is a measure of how much more water is being withdrawn by the indirect use than the direct use. For Example, the Germany Car facility is the most water efficient of all the car assembly facilities, but it has an IEWF of 50.9. This is due to Germany having an electricity resource profile that is heavy on coal and nuclear (80.9 and 98.59 m^3/MWh respectively). The Brazilian facilities have very low IEWF's because Brazil uses a substantial amount of hydroelectric (75.2%) which has a negligible water withdrawal. However, in the consumption calculations the reverse is true. The IEWF may be a useful concept because it enables automakers (or other manufactures') to prioritize which impacts from their facilities are causing constraints on the supply to a location. Although water withdrawn for electricity generation typically has a very high RFR (the vast majority of the water returns to the source for other users (Dooley et al., 2013)) it can still cause availability problems (UN, 2012).

9.2.3.2 Indirect Consumption

Indirect consumption due to electricity use is substantially lower than withdrawal. This is due to most types of electricity generation having very high RFR. From Table 54 those ratios can be as high as .981 (out of 1) for coal. Intuitively, the indirect consumption will be orders of magnitude lower for all of the electricity sources except hydroelectric, which has a water consumption of 17 m^3/MWh (Dooley et al., 2013; Semmens et al., 2014). For the indirect consumption of water due to electricity generation, no factor relating to the direct withdrawal will be made for two reasons: First, the overwhelming reporting of water use by automakers is direct withdrawal. Second, it does not appear to vary a great deal from facilities based on the calculation. The results based on Dooley et al (Dooley et al., 2013) consumption by electricity sources and IEA (IEA, 2012) profiles are shown in Table 59.

The indirect water consumption values calculated for the HAC facilities not located in Brazil are all within the range of 1.92-6.05 m^3/vehicle. These values broadly agree with the results by (Semmens et al., 2014) shown in Table 55. Facilities in Brazil have substantially higher consumption due to the increased use of hydroelectric power in that country shown in Table 56. The consumption by Brazilian facilities is in the range of high 20s m^3/production. The average consumption for the HAC facilities overall is 9.64m^3/production, but without the Brazilian facilities it is calculated as 5.04 m^3/production. The average of the automakers from Semmens' calculation was 2.21 m^3/vehicle which is below the average of the HAC facilities (not located in

Brazil), which tended to be close to the Daimler value of 3.69 m^3/year (Semmens et al., 2014). Given that the HAC profile is hypothetical and different sources from Semmens were used, the consumption values are reasonable.

Table 59 HAC Facilities Indirect Electricity Withdrawal and Consumption

HAC Profile		**Calculations based on IEA Profiles (IEA, 2012) and Resource Withdrawal (Dooley et al., 2013)**		
Facility	Production per Year [vehicles]	Total Electricity by Facility [MWh/year]	Total Indirect Consumption for Electricity Production [m^3/year]	Total Indirect Consumption per vehicle [m^3/vehicle]
USA Car	100,000	229,000	191,803	1.92
USA Truck	200,000	458,000	924,904	4.62
India Car	50,000	114,500	302,413	6.05
India Truck	100,000	229,000	604,825	6.05
Germany Car	200,000	458,000	1,001,900	5.01
Mexico Car	50,000	114,500	260,891	5.22
China Car	50,000	114,500	422,724	8.45
China Truck	100,000	229,000	845,442	8.45
Japan Car	100,000	229,000	453,426	4.53
Japan Truck	200,000	458,000	906,845	4.53
South Korea Car	500,000	1,145,000	1,425,371	2.85
Brazil Car	50,000	114,500	1,476,694	29.53
Brazil Truck	100,000	229,000	2,953,379	29.53
UK Luxury Car	2,000	4,580	5,759	2.88
Germany Engine	1,000,000	2,290,000	5,009,493	5.01
Brazil Transmission	1,000,000	2,290,000	29,533,685	29.53
Average	237,625	544,161	191,803	9.64
Average with No Brazil				5.04

9.2.3.3 Indirect Water Use from Electricity Discussion

The indirect water either withdrawn or consumed by the electricity generation for automobile production is an impact that is not currently covered in CDP Water Disclosures (CDP, 2014) of CSR's electricity (BMW, 2014b; Fiat-Chrysler, 2014; Ford, 2014a; GM, 2014a; Nissan-Renault, 2014; Peugeot, 2014; VW, 2014d). Despite this, the indirect use in electricity generation can be orders of magnitude larger than the direct withdrawal by automotive manufacturing facilities. The use of indirect withdrawal for energy generation is not typically included when calculating life-cycle-assessments of the impact of vehicles, but indirect water consumption is included for some life-cycle-assessments (Semmens et al., 2014).

Including the indirect withdrawal due to electricity generation can potentially be used to show the benefits of switching from non-renewable sources to renewable sources, excluding hydroelectric due to the dramatic consumption (17 m^3/MWH). Solar and wind power can dramatically reduce the indirect water withdrawal and consumption, but the effect is more pronounced in the indirect withdrawal. In Table 60, the HAC USA Car facility is compared with a facility called Solar Country Car. The only difference between the two facilities is the USA Car facility uses the USA electricity source profile from IEA (IEA, 2012) and the Solar Country Car facility uses entirely solar (PV) power.

Table 60 USA Car Compared with Solar Powered Car Facility

Facility	Total Indirect Withdrawal for Electricity Productior [m^3/year]	Total Indirect Consumption for Electricity [m^3/year]	Total Indirect Withdrawal per Vehicle [m^3/vehicle]	Total Indirect Consumption per Vehicle [m^3/vehicle]
USA Car	13,014,595	365,696	130	3.66
Solar Country Car	4,580	4,580	0.046	0.046
Difference	13,010,015	361,116	130.100	3.611

The difference in indirect water withdrawal and consumption is drastic, particularly the withdrawal, which is over 2000x times greater for the USA Car facility. Even the indirect consumption by USA Car is over 80x the indirect consumption by the facility that uses exclusive solar power. The electricity usage to manufacture cars and the energy profile of the countries in which the facilities are located is an underrated aspect of the water impacts of automotive manufacturing.

9.3 Workers Indirect Water Use

To calculate the indirect water usage of workers, the HAC water profile can be used to give a reasonable value for number of workers and their production intensity. Those values are based on worker information from BMW, Hyundai, GM, and VW's public reporting (BMW, 2014a; GM, 2014a, 2014b; Hyundai, 2014; USA, 2014; Volkswagen, 2014a). Those companies provide enough information about their operations publically to estimate the worker and water intensities of production. From those values, indirect water withdrawal caused by workers can be calculated using the FAO AquaStat database for water withdrawal averages by country.

9.3.1 Water Withdrawal by Country

For the purposes of comparing the water usage by the production facilities and the workers' indirect use, water withdrawal will be used from Table 61 and the water accounting definitions from Schornagela (Joost Schornagela, 2012). The reason withdrawal will be used for comparison is because the FAO database numbers are strictly withdrawal, and to do as close comparison as possible, the facilities withdrawal will be used as well. Additionally, withdrawal is the useful water use value to examine because withdrawal is what limits the availability of water in a region or location (Joost Schornagela, 2012).

Table 61 FAO Water Withdrawal by Country

per Capita Water Withdrawal by Country Average		
Country	FAO Water Withdrawal per Capita	
Brazil (FAO, 2014a)	376.7	m^3
China (FAO, 2014b)	406.0	m^3
Germany (FAO, 2014c)	386.5	m^3
India (FAO, 2014d)	615.4	m^3
Japan (FAO, 2014e)	713.2	m^3
Korea Republic of (FAO, 2014g)	549.0	m^3
Mexico (FAO, 2014f)	664.5	m^3
United Kingdom (FAO, 2014h)	212.9	m^3
USA (FAO, 2014i)	1,575.0	m^3

9.3.2 Water Withdrawal by Sector and Region

Water withdrawals globally are primarily for agricultural purposes, as shown in Figure 112 and Figure 113. Globally, agriculture uses 70% of the total water withdrawn (AQUASTAT, 2015). Industrial uses account for 19% of the total, and municipal withdrawal is only 11% (AQUASTAT, 2015). Figure 113 shows that country average mixes are significantly different from the sum of all withdrawals shown in Figure 112. This is due to a variety of mixes of industry use by region, which is shown in Table 62.

The percentages for sector withdrawals vary greatly by region (Table 62). This is significant because for industrial operations, it is important to know what other activities are using water in the region. For example, in North America and Europe, over half of the water withdrawn is for industrial purposes. Unlike most of the rest of the world, industrial operations in those regions will not be competing with agriculture and municipal sources as much. The other stakeholders in an area do impact the scrutiny with which water use is judged (UN, 2012).

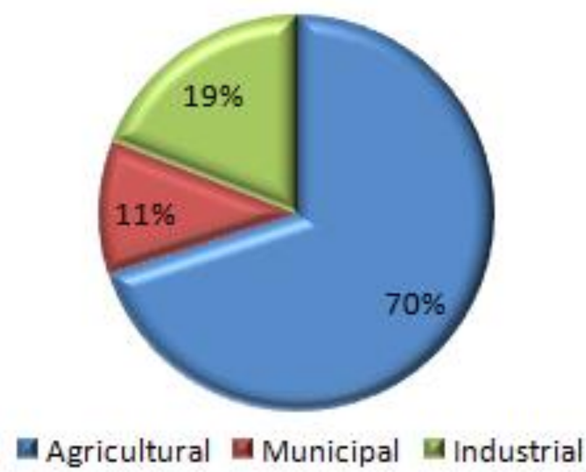


Figure 112 Global Sum Percentage of All Withdrawals (AQUASTAT, 2015)

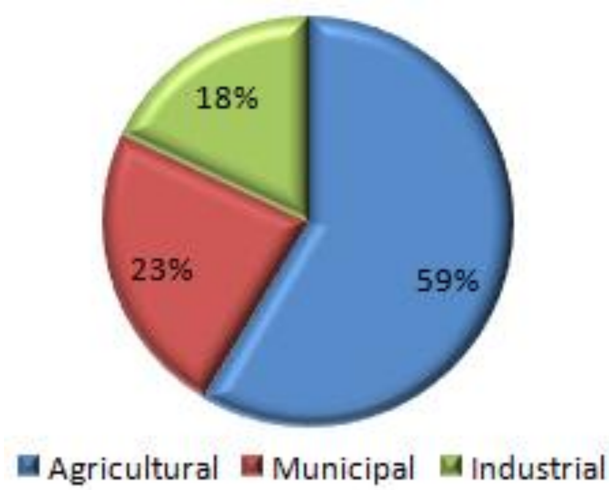


Figure 113 Average of Country Withdrawal Percentages (AQUASTAT, 2015)

Table 62 Withdrawal Sector by Region (Note the prevalence of agriculture in most regions) (AQUASTAT, 2014)

	Municipal	Industrial	Agricultural
Africa	13%	5%	82%
North America	14%	43%	43%
Central America	28%	9%	63%
South America	17%	12%	71%
Asia	9%	10%	81%
Europe	22%	57%	22%
Oceania	26%	15%	60%

9.3.3 Indirect Worker Withdrawal Calculation

The first step in understanding the withdrawal by the employees is to take the average withdrawal by country from the FAO AquaStat database and calculate the total withdrawal by employees for the HAC facilities using Equation 14. The '# of Employees' for HAC facilities is based on actual public worker profiles from automotive manufacturing companies.

Equation 14 Withdrawal by Employees Calculation

$$Withdrawal\ by\ Employees = \#\ of\ Employees * Withdrawal\ per\ \mathrm{Capita}\ from\ FAO$$

9.3.4 Employee Water Factor

In order to use the FAO data to estimate the withdrawal of the employees of a facility, it is important to note that the absolute value of the withdrawal is not necessarily a good indicator of the water use. For example, the HAC facility South Korea Car has substantially higher production than any other facility in the HAC (2.5x as many as any other vehicle production facility) and comparing the total withdrawal of the employees of that facility is not useful because it employs by far the most employees (over 1,000 more than any other). There is a need for a metric to describe the efficiency of the workers and their water use as it relates to production.

In order to create a metric, a simple equation was created in order to understand the relationship between the water withdrawn by a facility and the water withdrawn by the employees, and is shown in Equation 15. This equation takes into account the FAO values for per person water withdrawal and the total employees from Equation 14, and essentially scales that value in relation to the facility withdrawal, which directly correlates with the production of the facility.

Equation 15 Employee Water Factor Calculation

$$Employee\ Water\ Factor = \frac{Withdrawal\ by\ Employees}{Facility\ Withdrawal}$$

From Equation 15, it becomes apparent that the facilities with the highest Employee Water Factor (EWF) have the greatest amount of indirect water use by employees compared to their facilities' direct withdrawal. The EWF is impacted by every variable in the table, as well as the FAO AquaStat values for average per person withdrawal. The 'm^3 water/production' influences the water withdrawal by the facility, and the 'Prod/Year/Worker' is based on automakers public data, which determines the 'Employees' at each facility. The number of 'Employees' is used to calculate the 'Withdrawal by Employees'. All of the factors together make the EWF. The results of the EWF calculation and the relevant HAC profile information are shown in Table 63. The EWF values are colored to distinguish which facilities have the highest and lowest values of EWF with red corresponding with high values and green with low values.

Table 63 HAC Water Withdrawal, Production, Water Intensity, and Employee Water Factor (EWF does not follow the color code for stress states)

Hypothetical Automotive Company (HAC) Water Data							
		Vehicles					
Facility Name	Facility Withdrawal	Production	Employees	Withdrawal by Employees	Prod/Year/ Worker	m^3 Water/ Production	Employee Water Factor
USA Car	400,000	100,000	2,222	3,500,000	45.0	4.0	8.75
USA Truck	800,000	200,000	4,444	7,000,000	45.0	4.0	8.75
India Car	200,000	50,000	833	512,833	60.0	4.0	2.56
India Truck	400,000	100,000	1,667	1,025,667	60.0	4.0	2.56
Germany Car	500,000	200,000	5,714	2,208,571	35.0	2.5	4.42
Mexico Car	200,000	50,000	1,111	738,333	45.0	4.0	3.69
China Car	200,000	50,000	833	338,333	60.0	4.0	1.69
China Truck	400,000	100,000	1,667	676,667	60.0	4.0	1.69
Japan Car	400,000	100,000	1,667	1,188,667	60.0	4.0	2.97
Japan Truck	400,000	100,000	1,667	1,188,667	60.0	4.0	2.97
South Korea Car	2,000,000	500,000	8,333	4,575,000	60.0	4.0	2.29
Brazil Car	200,000	50,000	3,333	1,255,667	15.0	4.0	6.28
Brazil Truck	400,000	100,000	6,667	2,511,333	15.0	4.0	6.28
UK Super Luxury Car	110,000	2,000	4,000	851,600	3.0	55.0	7.74
Germany Engine	200,000	1,000,000	2,500	966,250	400.0	0.2	4.83
Brazil Transmission	200,000	1,000,000	2,500	941,750	400.0	0.2	4.71

9.3.5 Combining EWF with per Capita Source

Different countries can have significantly different water use profiles, as shown in section 9.3.2. For the countries in which the HAC operates, the ratio of agricultural, municipal, and industrial water use are shown in Figure 114.

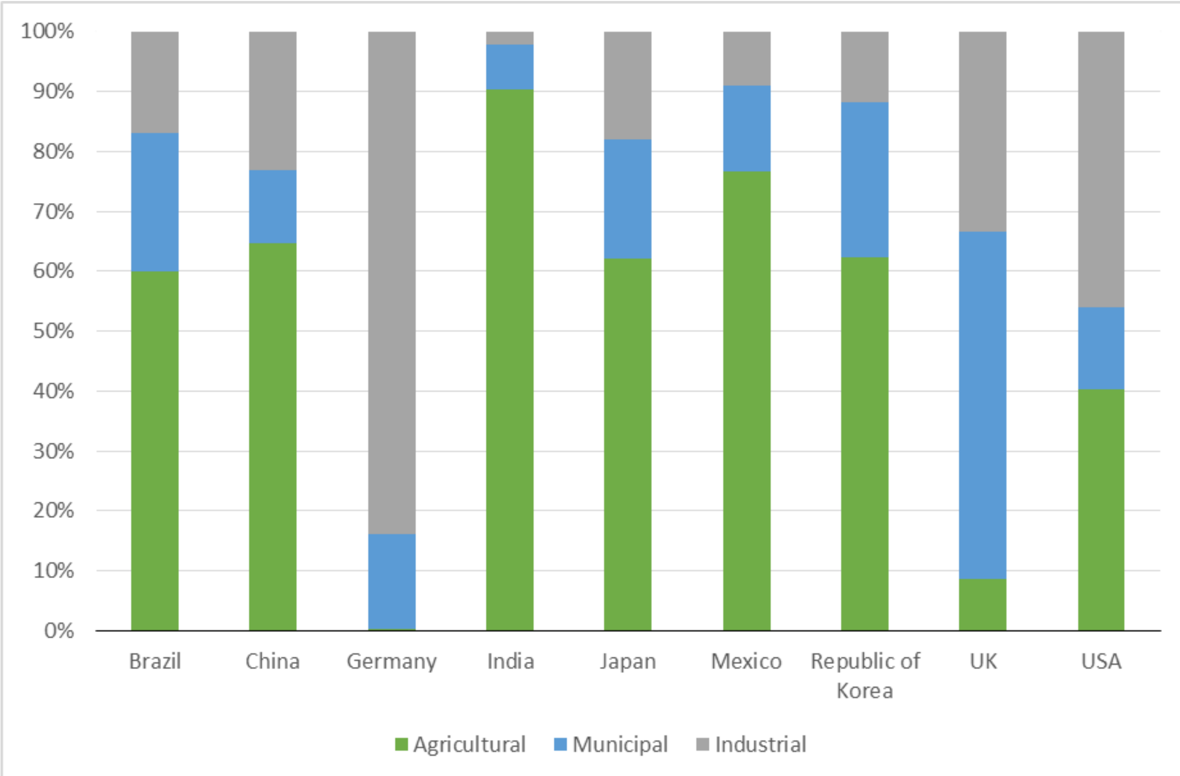


Figure 114 Water Withdrawal by Sector Profiles for Selected Countries (FAO, 2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2014g, 2014h, 2014i)

Figure 114 shows that some countries have radically different water use profiles. For example, Germany uses 83.9% of its' total water withdrawal for industrial purposes and only .3% for agriculture (FAO, 2014c). Conversely, India uses 90.4% of its' total water withdrawal for agriculture, and only 2.2% for industrial purposes. Combining this information with the EWF, it is possible to calculate EWF for agricultural, municipal, and industrial purposes, shown in #. The values for each type of EWF are rounded to one decimal place, and each factor is the percentage of the EWF that goes to the sector described. For example, the EWF for USA Car is 8.8. The EWF Agricultural is 40.2% of the original EWF because of the per capita withdrawal for the USA, 40.2% is for agricultural purposes (FAO, 2014i).

Table 64 EWF values for different sectors of withdrawal for HAC facilities

Facility	Employee Water Factor	EWF Agricultural	EWF Municipal	EWF Industrial
USA Car	8.8	3.5	1.2	4.0
USA Truck	8.8	3.5	1.2	4.0
India Car	2.6	2.3	2.1	1.9
India Truck	2.6	2.3	0.2	0.1
Germany Car	4.4	0.0	0.7	3.7
Mexico Car	3.7	2.8	0.5	0.3
China Car	1.7	1.1	0.2	0.4
China Truck	1.7	1.1	0.2	0.4
Japan Car	3.0	1.8	0.6	0.5
Japan Truck	3.0	1.8	0.6	0.5
South Korea Car	2.3	1.4	0.6	0.3
Brazil Car	6.3	3.8	1.4	1.1
Brazil Truck	6.3	3.8	1.4	1.1
UK Luxury Car	7.7	0.7	4.5	2.6
Germany Engine	4.8	0.0	0.8	4.1
Brazil Transmission	4.7	2.8	1.1	0.8

Dividing the EWF into the three different withdrawal sectors for the HAC allows the EWF to have further meaning. For example, in the USA, the municipal withdrawal is not significant compared to the agricultural and industrial withdrawal. For mitigating water stress near the USA Car and Truck facilities, engaging employees about their own use will only be able to help with the municipal withdrawal, which is not as large as the agricultural or industrial EWF. From Table 64, it is apparent that the ideal facility to engage employees about their personal water use is the UK Luxury Car facility. It's EWF municipal value of 4.5 is much greater than any other HAC facility. This means that employee engagement could significantly reduce the indirect water withdrawal by this facility.

9.3.6 Usefulness of Employee Water Factor

9.3.6.1 Direct Interpretation of the EWF

This is a helpful indicator because it allows the HAC (or any automotive manufacturing company) prioritize mitigation responses. For example, the EWF factor can be used for the HAC (or any automotive company) to the relationship between employees' water withdrawal for their personal uses compared to the water withdrawal. This factor does not mean that a facility is using water inefficiently; what it measures is if the primary withdrawal driver of a facility is the facility itself, or the employees' indirect water withdrawal. This factor becomes apparent when viewing Table 63. The lower values for HAC facilities were for China, India, Japan, and South Korea and were around 2 EWF. This means that the workers are only withdrawing about 2x the water the facility uses for the personal use. This corresponds with very low per capita use numbers from those countries and having a high production per worker per year figure. The facilities with the highest values of EWF are USA Car, USA Truck, UK Super Luxury, Brazil Car, and Brazil Truck, with values from 4-9 EWF. These facilities' workers are withdrawing 4-9x as much water for personal use compared to the amount the facility uses for vehicle production. Because of this, these facilities would benefit most from employee engagement about water use outside of the facility; the facilities may not benefit as much from direct investment in the reduction of water use from the facility. A reduction in the withdrawal in the local area of a facility can inherently improve the water risk and stress situation (UN, 2012).

The EWF as a standalone metric helps the HAC identify the facilities, which will benefit the local water supply more with employee engagement for water reduction than reducing the facilities' usage directly. In other words, in the facilities with high employee water factors the worker indirect withdrawal dwarfs the direct usage of the facility.

9.3.6.2 Scaling the EWF with Physical Risk from Aqueduct

Relating the EWF with the physical risk of available water provides insight into prioritizing which facilities have both a high EWF and are at higher risk for disruptions in supply. Again, lowering the withdrawal in the local water supply helps to alleviate water risk issues (UN, 2012). In order to do this type of calculation, the EWF would have to be included in a calculation with a stress or scarcity type of rating from one of the tools. As the EWF is related to the physical supply of water, the BWS from Aqueduct has been selected to serve as the measure to help prioritize facilities with both high stress/risk and a high EWF. Aqueduct BWS was chosen for a variety of reasons: it is the most recent scientifically collected stress or scarcity data (Paul Reig, 2013), it is the highest resolution of all the metrics available (WRI, 2014), and it follows the generally accepted use of using Total Withdrawal and Total Available as opposed to consumption (WRI, 2014). As the EWF is also based on withdrawal, this alignment helps keep the analysis straightforward. The new metric, Employee Mitigation Factor (EMF), is calculated by multiplying the stress state value from BWS with the EWF, and is shown in Equation 16.

Equation 16 Employee Mitigation Factor Calculation

$$EMF = BWS * EWF$$

9.3.6.3 Interpretation of EMF

The EMF is basically a score of how high the EWF and BWS metrics are. If the value of EMF is high, then there is some combination of substantial risk (according to Aqueduct) and the employees withdrawing significantly more than the facility. If the EMF is high, then that facility would benefit from employee engagement about water use. For example, the HAC has an average

EMF of 11; the facilities that are significantly above that value have some combination of high BWS and EWF that results in a high EMF. Facilities that have a high EMF could be prioritized for employee engagement as a means to mitigate the water stress in that locality. The HAC facilities that fit that description are Brazil Car, Brazil Truck, Mexico Car, UK Luxury Car, Germany Engine, Germany Car, India Car, and India Truck.

Table 65 Employee Mitigation for the HAC Facilities

Employee Mitigation Factor based on Aqueduct BWS and EWF			
Facility	AQE Baseline Water Stress	EWF	EMF
USA Car	1	8.8	8.8
USA Truck	1	8.8	8.8
India Car	5	2.6	12.8
India Truck	5	2.6	12.8
Germany Car	3	4.4	13.3
Mexico Car	5	3.7	18.5
China Car	1	1.7	1.7
China Truck	1	1.7	1.7
Japan Car	4	3.0	11.9
Japan Truck	4	3.0	11.9
South Korea Car	5	2.3	11.4
Brazil Car	2	6.3	12.6
Brazil Truck	2	6.3	12.6
UK Luxury Car	2	7.7	15.5
Germany Engine	3	4.8	14.5
Brazil Transmission	2	4.7	9.4
Average	2.9	4.5	11.1

9.3.6.4 Alignment with Current Automakers

This analysis matches details from various automakers' corporate sustainability reports.

VW reported in the 2014 CDP Water Information Report (VW, 2014e): "Volkswagen Brazil is implementing an Environmental Educational Program in order to promote attitudes and skills necessary for the preservation and improvement of environmental quality. The program seeks to involve all employees from all Volkswagen Brazil plants and it consists of: A Communication Plan to all the employees through internal media or Distribution of "The Green Book" teaching how to be more environmentally friendly." Ford Motor Company reported in its 2013 CDP Water Information Report a great deal of employee engagement about water issues outside of its direct operations. In India: "Employees participated in a program at the DNA School, Thoraipakkam, focusing on water sustainability, which featured a Street Theater presentation by Ford employees and an awareness campaign for the local residents. " "Sanitation and water purification treatment facilities were installed at 7 villages around Ford India Limited by thirty Ford volunteers." (Ford, 2013) Ford also has "Our facilities in Mexico are located in water-stressed regions; our manufacturing facility in Cuautitlan, Mexico, for example, is already subject to water-withdrawal limitations." (Ford, 2013) Ford also stated that globally: "Increasing water scarcity means industrial needs can be at odds with community and environmental needs. Industrial facilities in water-stressed areas will have reduced access to water and/or may endure rising water costs."

Automakers engaging with employees about water use in the locations the automakers operate is a growing area of emphasis. This engagement will help the different companies brand value as well as help lower the stress in those localities (CDP, 2014). The EWF and EMF are useful metrics because they can allow companies to estimate which locations are likely to benefit most from the employee and/or community engagements.

9.4 Summary of Chapter 9

9.4.1 Discussion of Combined Results of Indirect Calculations

The indirect use of water for the HAC facilities exceeds or nearly matches the direct use based on the calculations for indirect employee withdrawal and either indirect calculation for electricity generation (but particularly withdrawal). The EWF Table 63 was developed to express the discrepancy in direct usage versus the indirect usage by employees. This factor was coupled with the AQE BWS to provide insight into which facilities are in areas where employee engagement may be a particularly useful mitigation strategy for manufacturers concerned about water supply based on the EMF Table 65. The indirect water withdrawal and consumption were calculated for all of the HAC facilities, and an additional hypothetical facility, based on public production information (See page 39 Section 4.2 HAC Profile), country electricity source profiles (IEA, 2012), and water use data for the different sources of electricity (Dooley et al., 2013). Based on the calculations done in this thesis, the indirect water withdrawal from electricity generation far exceeds the direct water withdrawal (typical values of 30x as much indirect withdrawal from electricity than direct withdrawal). Additionally, the water consumption is a significant factor, averaging 3.69 m^3/vehicle which is more than BMW withdraws to directly manufacture a vehicle, on average (2.18 m^3/vehicle (BMW, 2014b)). These factors are not typically shown in the CSR's of automakers (BMW, 2014b; Fiat-Chrysler, 2014; Ford, 2014a; GM, 2014a; Nissan-Renault, 2014; Peugeot, 2014; VW, 2014d), and their inclusions to further emphasize a holistic approach to water stewardship because these water use figures are significant and merit further study.

CHAPTER 10 SUMMARY, RECOMMENDATIONS FOR METRICS AND TOOLS, AND FUTURE WORK

10.1 Overview

This thesis introduces the context for examination of water issues in a corporate setting. Additionally, CDP reports and other sources examine why companies should be concerned about water issues. For example, 68% of CDP respondents reported "water poses a substantive risk to their business." (CDP, 2014) The use of the tools can help companies assess their risk and plan mitigation response (Paul Reig, 2013; WBCSD, 2011b; WWF, 2014a). Additionally, the results can be compared with CDP respondents to see how well the tools correlate with some known water risks and stresses. From there, additional indirect water use calculations that are not currently used in standard life-cycle-assessments, CDP reports, or Corporate Sustainability Reports were shown to be significant. Three new water metrics were shown, Employee Water Factor (EWF), Employee Mitigation Factor (EMF), and Indirect Electricity Withdrawal Factor (IEWF). With all of the results and calculations combined, the HAC (or any company) can gain a much deeper understanding of the water situation and take concrete steps to mitigate water risks.

10.1.1 Overview of Use for HAC

The main purpose of the three tools (Global Water Tool, Aqueduct, and Water Risk Filter) is to enable the user to understand the water risks and potential for environmental impact based on the usage of an organization. All of the tools can be used to attempt to determine which locations in an organization are located in areas with water scarcity (or another water risk). AQE and WRF both contain metrics for a variety of other risks such as Flood Occurrence or Media Coverage, as outlined previously in this thesis (Chapters 6 and 7).

10.1.2 Key Metrics Calculations and Datasets

According to the 1,064 respondents to the CDP Water Information Request, the top five water issues impacting operations were the following: Stress/Scarcity, Flooding, Drought, Quality, and Regulatory and Reputational Risks (CDP, 2014). Of those water issues, each tool's results were examined and compared for correlation to each other. Additionally, those results were compared with CDP respondents reports of impacts in different watersheds or countries (Analytics, 2014b; Water, 2015). Table 49 and Table 50 show statistics relating the different metrics available between all three tools.

Despite standardized water reporting for companies provided by CDP and integrated into the GWT (WBCSD, 2011c)and WRF (WWF, 2015c) the water metrics used by AQE (Paul Reig, 2013), GWT (WBCSD, 2011b), and WRF (WWF, 2014a) do not follow a standard set by a 3rd party, except for the Falkenmark Index for water stress in the GWT (Joost Schornagela, 2012).

In general, the results do need to be examined in depth to understand exactly what the results mean. At least one tool matched well with the locations where CDP respondents reported issues for each type of impact. Of the tools, the WRF did seems to have the most consistent results with CDP and had the largest set of metrics (WWF, 2014a). However, AQE did have advantages such as higher resolution, mapping of custom weights, and projections not available in the other tools (Paul Reig, 2013). The GWT does have a large collection of metrics, but only a few related to water issues that impact the operations of a company (WBCSD, 2011b).

10.2 Strength and Weaknesses of Water Tools

10.2.1 Aqueduct

Aqueduct's general usage plan is covered in Figure 6, and begins with the collection of location information for the facilities. Once the locations are input, Aqueduct allows the user to have a great deal of customization of weights and water metrics within the tool. The World Resource Institute, who created and operates Aqueduct, summarizes it as follows:

"(T)he Aqueduct Water Risk Atlas provides comparability across the globe acting to highlight areas of potential concern. These global metrics and associated maps can help identify water-related risks, and provide a picture of how they vary spatially across regions, countries, or continents. However, to understand the complete picture of the conditions on the ground, further study must evaluate each area's infrastructure and policy and management practices that might mitigate the identified water-related risks." (Paul Reig, 2013)

The strengths and weaknesses of the tools relate directly to decisions made when the layout of the tools was decided. For instance, it is not for water accounting, it tries to give the user an analysis of the water situation experienced at a given location.

10.2.1.1 Strength and Weaknesses of AQE

The strengths of AQE (WRI, 2014):

- Higher resolution than other tools
- Recent data for metrics
- Maps allow any combination of metrics to be plotted

- The metrics match well with CDP, except for Reg. & Rep.
- Projections of stress for a variety of scenarios and time frames
- Has all the impactful metrics mentioned by CDP
- Easiest to get results from

The weaknesses of AQE (WRI, 2014):

- No water accounting
- Reg. & Rep. Results did not match well with CDP
- Regions of ‘No Data’

10.2.2 Global Water Tool

The GWT does have a large set of metrics related to water, and it has the ability to map most of them. The GWT is limited in the metrics that the CDP reports as being impactful for companies (CDP, 2014). The GWT does have older datasets than the other tools and it does not have as many metrics that relate to the water situation at a facility as the other tools.

10.2.2.1 Strength and Weaknesses of GWT

The strengths of the GWT (WBCSD, 2011b):

- Expansive set of metrics
- Mapping water related metrics
- Raw values are available for every metric
- Water Accounting to help with reporting to CDP, other groups

- ARWS matches well with CDP stress states

The weaknesses of the GWT (WBCSD, 2011b):

- Limited metrics for water direct water impacts
- Some datasets are old, for example ARWS is from 1995
- Projections are only based on population change estimates
- No dataset has as high a resolution as AQE
- Regions of ‘No Data’

10.2.3 Water Risk Filter

The Water Risk Filter is an online tool that stores locations and their information and has maps of water metrics and other analyses. The same inputs to the GWT were input, albeit in a different fashion. The web-based WRF keeps the facilities in a list and the user fills out a survey of a variety of water-related questions. From the WRF: “This tool helps companies and investors ask the right questions about water. It allows you to assess risks and offers guidance on what to do in response.” (WWF, 2013)

The WRF was designed to be used by non-water experts. The tools tries to give as much output as possible with whatever input is given. For example, questions can be left blank, and it will not cause any errors. In addition, the weighing scheme is simple (and can be adjusted) and has preset values for a given industry. The preset default weights are from WWF experts, but the weights can be adjusted by the user to account for any company’s priorities. With the risks recalculated, that may result in a different risk profile for the entire organization. Armed with this information, the company executives could now take steps to reduce that risk and potentially help the company.

10.2.3.1 Strength and Weaknesses of WRF

The strengths of WRF (WWF, 2014a):

- Expansive set of metrics
- Mapping of metrics particular aspects, such as scarcity for a particular month
- Questionnaire is thorough examination of water issues at facilities
- Water accounting helps with reporting for CDP or other groups
- Matched CDP respondents results the best of the three
- Projection includes economic, population, and climate change
- Recent databases for metrics
- Continuously updated with new features and abilities

The weaknesses of WRF (WWF, 2014a):

- Lower resolution of data than AQE
- Difficult to get results from
- Regions of ‘No Data’

10.3 Recommendations for Water Metrics and Datasets

Water metrics generally fall into one of three categories: survey results, historical data, and measured data. The tools take information from databases of these three types and calculate different stress states based on those databases.

10.3.1 Current Metric Calculations for Stress and Scarcity

Water stress and scarcity are used interchangeably in some water reports, such as the CDP Global Water Report 2014 (CDP, 2014). Each tool handles the issue differently, and in the case of the WRF, stress and scarcity have the same calculation, just different databases. These differences are overviewed in Figure 115, Figure 116, and Figure 117.

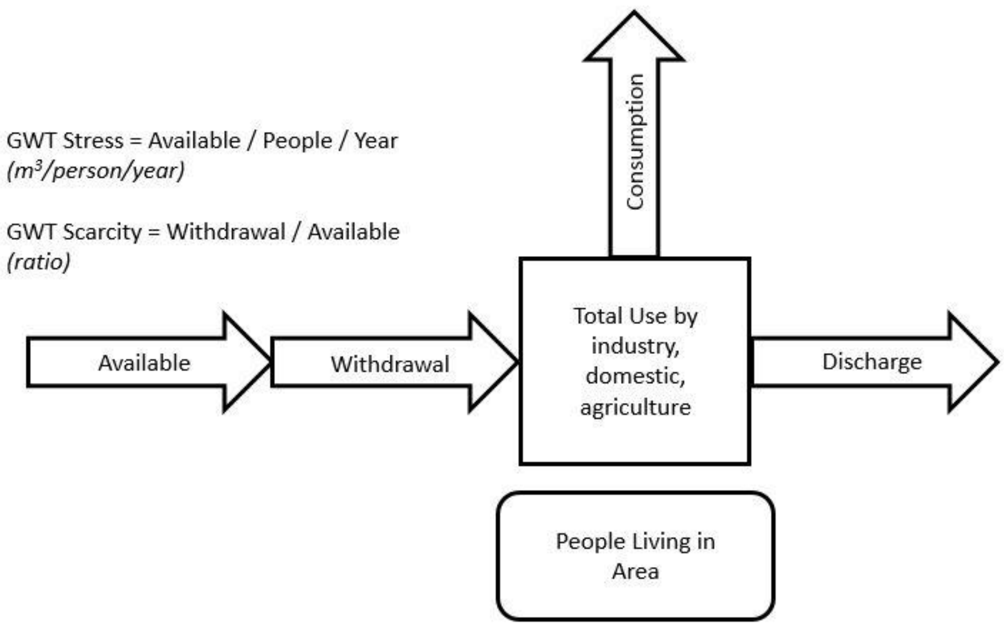


Figure 115 GWT Stress and Scarcity Calculation

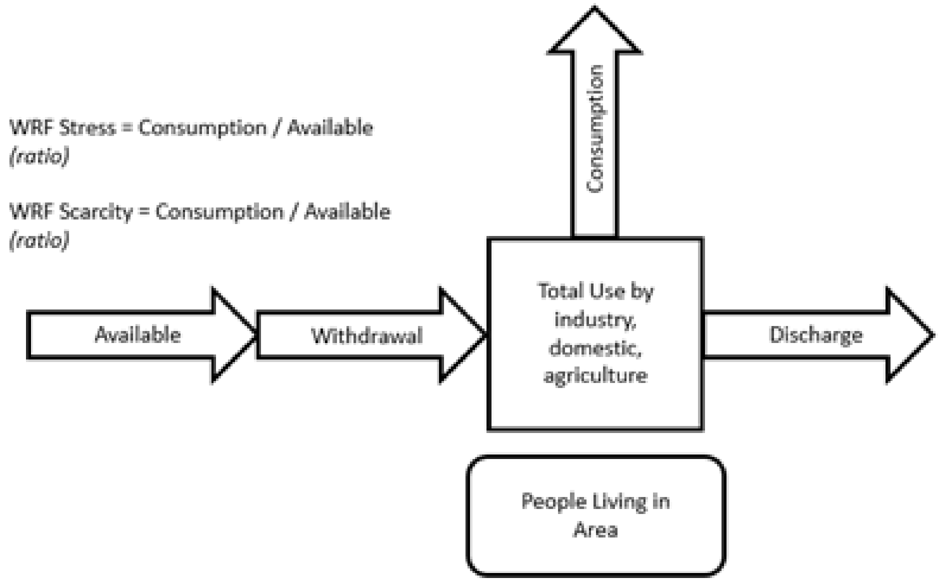


Figure 116 WRF Stress and Scarcity Calculation

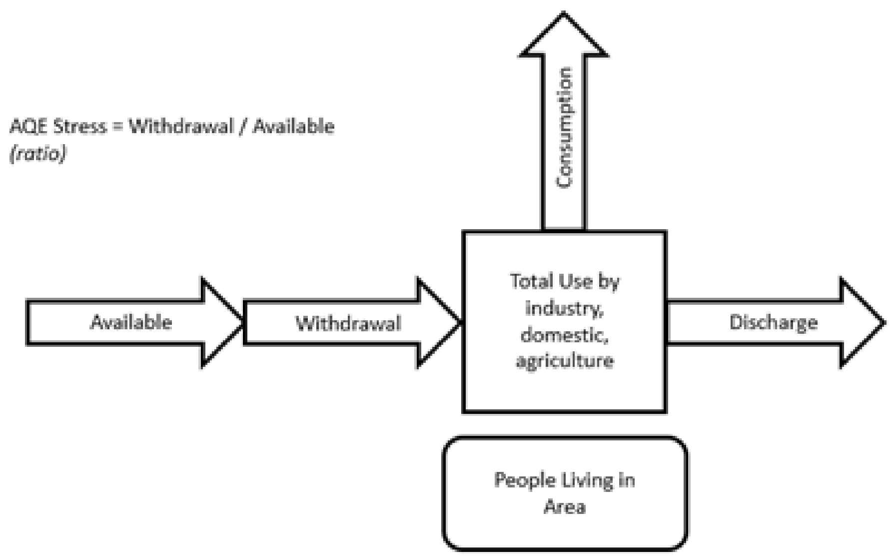


Figure 117 AQE Stress and Scarcity Calculation

The lack of consistency did not prevent the tools from outputting a stress state for each metric, which allowed for comparisons between tools and with the CDP reported issues. However, it does mean that each tool has to be individually understood in order for the results to be useful.

10.3.1.1 Problems with Current Calculations

The main problem is that the actual results of the tools cannot be compared; only the resulting state of risk/stress can be assessed. For example, it would not be useful to compare the Falkenmark index, as reported by GWT (WBCSD, 2011b), with the BWS results from AQE because the units for the Falkenmark index are m^3/person/year and the BWS is a ratio of withdrawal to available water (Paul Reig, 2013).

Another problem is the CDP respondents do not have to follow any given requirements to report an impact (Analytics, 2014b). Although the respondents use water tools and their own internal knowledge of issues, if water metrics were further standardized, it would be much more useful to compare results company-to-company or tool to tool. Water accounting (definitions for withdrawal, consumption, and use generally) and water Life Cycle Assessment calculations have been standardized by the ISO in ISO 14046 (ISO, 2014). Defining the water stress and risk metrics would be similarly useful, because then all tools and research would be operating around a set of defined calculations.

10.3.1.2 Recommendation for Stress Metric

Because of the inconsistency for stress and scarcity metrics, it would be better for reporting groups and companies to have consistent definitions for the metrics. This could be done similarly to the water accounting definitions outlined by Schornagela (Joost Schornagela, 2012). Schornagela also defined physical and economic water stress (Joost Schornagela, 2012), shown in Figure 118. The general idea of a ratio of water withdrawal with total available water is used by AQE (WRI, 2014) and has been used in a variety of other water stress reports (Berrittella et al., 2007; Falkenmark et al., 1989; Joost Schornagela, 2012; Mueller et al., 2014; Rijsberman, 2006; UNDESA, 2013). Additionally, water withdrawal may return to the water source, but any withdrawal makes the water less *available* for other users in a location (Falkenmark et al., 1989; Joost Schornagela, 2012). For those reasons, the AQE and Schornagela version of water stress is recommended above the other versions (Falkenmark and WRF by consumption) and is shown in Equation 17. Part of the justification for using this method is simply the problems with the other methods used by GWT and WRF.

Equation 17 Recommended Calculation for Water Stress

$$Water\ Stress = \frac{Total\ Withdrawals}{Total\ Available}$$

water \ stress	Physical	Economic
saline	$\frac{W_s}{H_s} > 1$	$\frac{W_s}{S_s} > E_s$
brackish	$\frac{W_b}{H_b} > 1$	$\frac{W_b}{S_b + C_b + U_b} > E_b$
fresh*	$\frac{W_f}{H_f} > 1$	$\frac{W_f}{S_f + C_f + U_f} > E_f$

$W_{s,b,f}$: total needed water withdrawal from basin

$H_{s,b,f}$: hydrologically renewable water availability through existing infrastructure of water basin

$S_{s,b,f}$: sustainable** water availability in basin

$C_{b,f}$: sustainably conveyed water from other basins

$U_{b,f}$: sustainably upgraded water

$E_{s,b,f}$: economic water stress threshold for operation

subscripts designate saline (s), brackish (b) or fresh** (f) water

* excludes rainwater in soil

** taking into account environmental, social and economic dimensions

Figure 118 Water Stress Definitions from Schornagela (Joost Schornagela, 2012)

10.3.1.3 Recommendation for Water Scarcity

For all of the same reasons that water stress should potentially be defined by Equation 17, scarcity could be defined by Equation 18. Defining scarcity as a ratio of the total consumption to total available adds a distinct difference between the two metrics. This also provides a distinction so that scarcity and stress can be examined separately and the advantages and disadvantages could be studied further. That being said, the WRF GLOWASIS Stress uses the same concept as Equation 18 and it returned states that matched the CDP respondents stress/scarcity reporting.

Equation 18 Recommended Calculation for Water Scarcity

$$Water\ Scarcity = \frac{Total\ Consumption}{Total\ Available}$$

10.3.1.4 Summary of Stress and Scarcity Recommendations

Both of these types of calculations correlated well with CDP reporting impacts Table 33 (Water, 2015). Both stress and scarcity (as defined in Equation 17 and Equation 18) are used by tools examined in this thesis (Paul Reig, 2013; WWF, 2014a), and are used in separate studies examining water use (Berrittella et al., 2007; Herbst, 2009; Joost Schornagela, 2012; Mueller et al., 2014; Rijsberman, 2006; Semmens et al., 2014). Additionally, for both stress and scarcity, updated, scientifically measured data is available from a variety of sources so that changes in the withdrawal, consumption, or availability could be updated in the tools. Water tools may benefit from some standardization of stress and scarcity to take advantage of those properties.

10.3.2 Current Calculations for Other Metrics and Datasets

The other metrics in the tools were typically just a plot or examination of a set of data collected externally. For example, the Flood Occurrence metric in both AQE and WRF is a collection of flood records by the Univ. of Colorado and plotted through the tool (Brakenridge, 2015; Paul Reig, 2013; WWF, 2014a). This is useful information and a helpful guide for the risks exposed to a facility. However, these types of metrics still need to be kept up to date. Regardless of the calculation or method of presenting the data, having up to date information is key, because water situations do change, and are generally projected to get worse (UN, 2012; UNDESA, 2013).

10.4 Overview of Indirect Results

10.4.1 Overview of Indirect Impacts

For automotive manufacturing in general, the water use is an important resource because it impacts cost, brand image, and the relationship with the local actors near facilities (CDP, 2014). Having a complete understanding of the indirect water use is important, because even if the water is not directly withdrawn for a facility, that water is removed from the source and is unavailable for other purposes, which can increase the stress in a location (Joost Schornagela, 2012; Rijsberman, 2006). CDP has begun asking responders to report on supply chain water use and if indirect water is taken into account, but there is no explicit definition of what exactly constitutes indirect water use (CDP, 2014). This thesis examined two indirect water users that can have a significant water impact: workers and electricity generation.

The indirect use of water for the HAC facilities exceeds or nearly matches the direct use based on the calculations for indirect employee withdrawal and either indirect calculation for electricity generation (but particularly withdrawal). The EWF (Table 63), EMF (Table 30), and IEWF (Table 58) were developed to express the discrepancy in direct usage versus the indirect usage by employees. Based on the calculations done in this thesis, the indirect water withdrawal for employees can be substantially higher than direct withdrawal by the facility Table 63.

Additionally, withdrawal from electricity generation far exceeds the direct water withdrawal (typical values of 30x as much indirect withdrawal from electricity than direct withdrawal).Finally, the water consumption is a significant factor, averaging 3.69 m^3/vehicle which is more than BMW withdraws to directly manufacture a vehicle, on average (2.18 m^3/vehicle (BMW, 2014b)). These factors are not typically shown in the CSR's of automakers (BMW, 2014b; Fiat-Chrysler, 2014; Ford, 2014a; GM, 2014a; Nissan-Renault, 2014; Peugeot, 2014; VW, 2014d), and their inclusions to further emphasize a holistic approach to water stewardship because these water use figures are significant and merit further study.

10.5 Recommendations for Indirect Calculations

Reporting employee numbers and electricity usage as part of water disclosure reports can help give a more complete picture of the total water use by a company in a given locations. The indirect water uses can account for significantly more water withdrawal than the direct operations, as shown in Table 63 for employees and Table 58 for electricity. This could help organizations, such as CDP, gain a better understanding of the indirect effects of different industries. Companies may not want to disclose all of the employee numbers, electricity usage, or complete water picture for all or any specific facilities. This is where the factors created in this thesis come in. The EWF, EMF, and IEWF do not reveal any details about operations specifically. What they represent are ratios that describe the particular indirect withdrawal in relation to the withdrawal by the facility. It essentially lets the public know if the indirect impact is more significant than the facility's usage without revealing information a company may want to keep proprietary. By reporting the EWF and IEWF, a company can contribute to the general knowledge of the watershed or country's water situation.

10.6 Recommendations for Future Work

An area of untapped potential is coupling the CDP reported risk factors with a water tool. This could include some results in the tools output, essentially acting as “Yelp!” for water issues. The tools do have scientifically collected data, but the potential to include information from companies or organizations operating in areas of current operations could help serve in everyone’s best interest. If a company is already experiencing water stress issues, the company would prefer to have fewer competitors for that water supply, and other companies may not want to move there is the water supply is restricted. The local stakeholders would also likely experience the same stress, and would benefit from less competition for the water supply.

An ideal water tool would combine the best features of each tool and use the stress and scarcity definitions recommended in this thesis (Equation 17 and Equation 18). The resolution of AQE is substantially better than either the GWT or WRF. AQE and WRF both do a good job of keeping their databases updated, unlike the GWT, which uses some data from 1995 (Paul Reig, 2013; WBCSD, 2011b; WWF, 2014a). AQE enables the user to quickly receive results, because AQE require the least input information. The user can adjust weights, make maps, and export results based on the location very simply. However, the water accounting abilities of the WRF and GWT are useful and AQE has no water accounting (Paul Reig, 2013; WBCSD, 2011b; WWF, 2014a). An ideal water tool would perform all of those functions and integrate real-world reports of water issues.

10.7 Conclusions

Throughout this thesis, it was shown that an in-depth understanding of the water tools was key for understanding exactly what the tools were reporting. The best example of this was the distinction between the country-level and watershed-level data in GWT. That example showed that even within a tool, the results needed to be understood because the results sometimes conflicted (Figure 7 and Figure 8). Additionally, an in-depth understanding of how all the tools worked allowed their results to be compared with real-world reported impacts from CDP. Performing the statistical analysis showed which tools were giving useful information based on the metrics that CDP reported as the significant ones for companies' operations (CDP, 2014). Those results showed that the WRF matched real-world results slightly better than AQE, which still matched for nearly all metrics on Table 33 (See Chapter 8).

The in-depth understanding coupled with the real world information provides guidance for the HAC (or any company) on how to use their own internal knowledge and couple that with the tools to gain a better understanding of their water situation. With that understanding, mitigations steps can be taken to minimize the risk to operations and the water supplies in areas where companies operate. Additionally, public disclosure can take place to encourage industry to be stewards of the water supply. The statistical analysis can help show which metrics from which tools match real world results closer, which inspires confidence in the tools when there is no CDP response to compare with.

The recommendations for indirect water reporting outlined in this thesis are unique, and could potentially encourage companies to report more about their indirect water use than they currently do. There is a precedent for reporting of indirect $C0_2$ emissions, but not for indirect water use (Fiat-Chrysler, 2014; Nissan-Renault, 2014; Peugeot, 2014; VW, 2014d). Part of that could be a lack of companies' desire to report detailed water use information that is needed to estimate the overall use. The indirect factors (EWF and IEWF) both keep the actual use proprietary, yet enable the company to report if the indirect water use is significant relative to industrial direct withdrawal.

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APPENDIX A

BRAZIL CAR SURVEY EXAMPLE

WRF Brazil Car Survey and Answers (text only)

Brazil Car Survey (WWF, 2015b)

Company related risk

Risk Indicator

Physical Risk

Scarcity (Quantity)

- 1. Importance of having sufficient amounts of clean freshwater available for the production/ operational site's operations

- 2. Problems the company has/had withdrawing/obtaining the required amount of water for its operations

2a. If yes, please explain:

- 3. Total annual amount of freshwater withdrawn either directly from a water source or through the municipal supply (m³/year)

200,000

Please indicate the percentage of the total amount of freshwater that your company withdraws for its production/ operational site per water source:

0 1-10% 11-50% 51-90% 91-100%

3a. Surface (e.g. River/ Lake)

3b. Ground-water

3c. Municipal Supply

3d. Rainwater

3e. Non-freshwater (e.g. saltwater)

3f. Unknown Source

- 4. Percentage of the total amount of withdrawn water that is recycled or reused (used more than once). Maximum answer for this indicator is 100%

25-50%

- 4a. Total amount of waste water discharged? (m^3/year)

100,000

Please indicate the percentage of the total amount of waste water that your company discharges into the different receiving bodies:

0 1-10% 11-50% 51-90% 91-100%

4b. Ocean

4c. Surface (e.g. River/ Lake)

4d. Subsurface/ Well

4e. Off-Site Water Treatment

4f. Other or unknown

Pollution (Quality)

- 5. Typical level of water pollution caused by this industry

Some pollution

5a. Average ecotoxicity

122,933.61

5b. Average eutrophication

0

5c. Average acidification

0.241

- 6. Requirement of treatment/ purification of the water the company withdraws before use in operations

- 7. Percentage of the withdrawn freshwater that is discharged with some level of pollution

- 8. Quality measurements of the water the company withdraws and discharges by the company itself or an external company

8a. If no, please explain:

Physical risk of suppliers

- 9. Average water intensity of suppliers to this industry

Supplying industries to the industry are dependent on large amounts of water

9a. Country of origin of the main supplier(s) to the company

Brazil

- 10. Estimated total annual amount of freshwater withdrawn by suppliers to this specific company or facility (m^3/year)

- 11. Average level of water pollution caused by suppliers to this industry

Highly polluting supplying industries, based on the three pollution indicators

11a. Average ecotoxicity

717,764.34

11b. Average eutrophication

0

11c. Average acidification

0.626

- 12. Flexibility of the company to change its main supplier(s)

Impact on ecosystem

- 39. Conduction of environmental flows studies and adaption of operations to simulate the original environmental flows (e.g. seasonal flows) in order to limit the impact of the hydropower station

Regulatory Risk

- 13. Compliance of the company to legal waste water quality standards

13a. If company does not meet discharge quality requirements, please explain which elements do not comply (e.g. COD/ BOD/ TSS/ Chemicals/ Temperature/ Metals/ etc.).

- 14. Has the company paid any penalties or fines for significant breaches of discharge regulations within the last 5 years?

14a. If yes, please describe the incident(s):

- 15. Is the company exposed to planned or potential significant regulatory changes?

15a. Other (please specify):

15b. Is there a strong enforcement of water related regulations in the area your company operates in?

Reputational Risk

- 16. Exposure of this specific facility to local/national media coverage criticizing for a possible water issue

- 17. Exposure of this specific facility to global media coverage criticizing for a possible water issue

- 18. Does the company know who the other key stakeholders (e.g. communities, other industries, agriculture etc.) are who are dependent on the water supply and quality within the water basin the company operates in?

- 19. Importance of the company as a water consumer in comparison to other stakeholders within the river basin (within 50km).

- 20. Engagement with other local basin stakeholders like municipalities, governments, companies, farmers and NGOs to solve water-related conflicts and to manage local water resources

20a. If yes, please specify

20b. Does an official forum or platform exist in which stakeholders come together to discuss water-related issues of the basin?

20c. If yes, please state the name

- 21. Involvement in any water-related disputes with other stakeholders in the basin within the last 5 years

- 22. Water policy, strategy and/or management plan of the company

- 23. Highest level of responsibility within the company for the policy, strategy and/or plan

- 24. Discussions of monitoring of (waste) water quantities and quality within top management

- 25. Contingency planning to be prepared to respond to water risks, such as supply disruptions, price increases and more stringent regulations

25a. If yes, please specify

- 26. Water-related actions taken at the operational/ production site in regard of improving its own operations

26a. Other (please specify):

- 27. Significant investments planned within the next 3 years which are related to water issues (e.g. water treatment plant, water recovery, water efficiency)

27a. If yes, please specify

For anonymous bench marking purposes

28. The annual (production) volume of output of this facility

28a. Unit

29. The annual (production) volume of output of this faciliy

Final comments (for internal use only)

30. The annual (production) volume of output of this facility